CHAPTER 3

THE STATE OF THE OBSERVING SYSTEM

Project Summaries, FY 2004 Progress, FY 2005 Plans

This chapter is comprised of FY 2004 progress reports followed by FY 2005 plans submitted by scientists funded by NOAA's Climate Observation Program. A request for annual progress reports was issued in late August 2004 (see Appendix D). Excerpts from the submitted reports are presented here summarizing efforts focused on enhancement of the global ocean observing system for climate.

The chapter begins with a report describing the Office of Climate Observation's Climate Observation Program, the primary sponsor of the documented projects, followed by a table of OCO-funded projects and their accompanying web sites. The reports that follow are in alphabetical order based on the Principal Investigator's last name.

PROGRAM OVERVIEW
FY 2004 PROGRESS

Office of Climate Observation, Climate Observation Program
by Mike Johnson, Office of Climate Observation, Silver Spring, MD

Introduction

This report provides an annual progress report and work plan for NOAA's Climate Observation Program. The program was initiated by the Office of Global Programs (OGP) with Climate and Global Change (C&GC) funding in 1998. Since then the program has grown to include funding accounted for within five separate budget lines. This report presents the composite Program as managed through the Office of Climate Observation (OCO).

Program Description

Goal and Objectives:
The goal of the program is to build and sustain a global climate observing system that will respond to the long term observational requirements of the operational forecast centers, international research programs, and major scientific assessments. The Climate Observation Program focuses on building the ocean component. The program objectives are to:

- document long term trends in sea level change;
- document ocean carbon sources and sinks;
- document the ocean's storage and global transport of heat and fresh water;
- document ocean-atmosphere exchange of heat and fresh water.

Specific issues, requirements, and customer need motivating the program:
The ocean is the memory of the climate system and is second only to the sun in effecting variability in the seasons and long-term climate change. In order for NOAA to fulfill its climate mission, the global ocean must be observed. At present, the Climate Observation Program is

arguably the world leader in supporting implementation of the *in situ* elements of the global ocean climate observing system.

The Climate Goal via the Climate Observation Program provides the major part of NOAA's contribution to the global component of the U.S. Integrated Ocean Observing System (IOOS). The observing system being put in place for climate requirements also supports global weather prediction, marine services, military applications, global and coastal ocean prediction, marine hazard warning systems (e.g., tsunami warning), and marine environmental monitoring, among other things. Many non-climate users also depend on the baseline composite system that is nominally referred to as the global ocean climate observing system.

The ocean climate observing system needs to have the capability to deliver continuous instrumental records and analyses accurately documenting:

- Sea level to identify changes resulting from climate variability.
- Ocean carbon content every ten years and the air-sea exchange seasonally.
- Sea surface temperature and surface currents to identify significant patterns of climate variability.
- Sea surface pressure and air-sea exchanges of heat, momentum, and fresh water to identity changes in forcing function driving ocean conditions and atmospheric conditions.
- Ocean heat and fresh water content and transports to: 1) identify changes in the global water cycle; 2) identify changed in thermohaline circulation and monitor for indications of possible abrupt climate change; and 3) identify where anomalies enter the ocean, how they move and are transformed, and where they re-emerge to interact with the atmosphere.
- Sea ice thickness and concentrations.

Present ocean observations are not adequate to deliver these products with confidence. The fundamental deficiency is lack of global coverage by the *in situ* networks. Present international efforts constitute only about 48% of what is needed in the ice-free oceans and 11% in the Arctic. The *Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC* concludes that "the ocean networks lack global coverage and commitment to sustained operations…Without urgent action to address these findings, the Parties will lack the information necessary to effectively plan for and manage their response to climate change." The *Strategic Plan for the U.S. Climate Change Science Program* calls for "complete global coverage of the oceans with moored, drifting, and ship-based networks."

The 2003 Earth Observation Summit raised to the highest levels of governments the awareness of the need for a global observation system. The climate question is high on the political agendas of many nations and can be answered authoritatively only by sustained earth observation. The Earth Observation Summit reaffirmed NOAA's leadership and commitment to fulfilling the need for global coverage and the Climate Observation Program is NOAA's management tool for implementing the ocean component.

In response to the Second Adequacy Report, international GCOS produce the *Implementation Plan for the Global Observing System for Climate in support of the UNFCCC* (GCOS-92). GCOS-92 was published in October 2004. It has been endorsed by the UNFCCC; and it is expected to be endorsed by the Earth Observation Summit III in Brussels, in February 2005. In particular:

1. The UNFCCC, Decision CP.10, "Encourages Parties to strengthen their efforts to address the priorities identified in the [GCOS] implementation plan, and to implement the priority elements …"

2. The draft *Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan*, 6-year targets include: "Support implementation of actions called for in GCOS-92."

OCO's *Program Plan for Building a Sustained Ocean Observing System for Climate* is in complete accord with GCOS-92 and provides the framework for NOAA contributions to the international effort. In particular 21 of the specific actions listed in the GCOS-92 ocean chapter (pages 56-84) are being acted upon by the Climate Observation Program in cooperation with the implementation panels of the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), the International Ocean Carbon Coordination Project (IOCCP), and the Climate Variability and Predictability (CLIVAR) Program. These specific GCOS-92 actions now provide an excellent roadmap to guide observing system work over the next five years. GCOS-92 is accessible via link from the OCO web site: www.oco.noaa.gov -- click on "Reports & Products."

Partnerships:
The Climate Observation Program is managed as an inter-LO, interagency, and international effort. The Climate Goal, through the Climate Observation Program, provides the backbone of the Global Component of NOAA's Integrated Ocean Observing System (IOOS) project. The work of 19 distributed centers of expertise and 151 people is supported through the Program. Presently most NOAA contributions to the global system are being implemented by the OAR laboratories, joint institutes, universities and business partners. NOS, NMFS, and NWS maintain observational infrastructure for ecosystems, transportation, marine services and coastal forecasting that do or have potential to contribute to climate observation. NOS sea level measurements in particular provide one of the best and longest climate records existent. NESDIS data centers are essential. NMAO ship operations are necessary for supporting ocean work. NESDIS and NPOESS continuous satellite missions are needed to provide the remote sensing that complements the *in situ* measurements.

International and interagency partnerships are central to the Climate Observation Program implementation strategy. All of the Program's contributions to global observation are managed in cooperation internationally with the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), and nationally with the U.S. Integrated Ocean Observing System (IOOS). NSF has initiated their Ocean Observatories Initiative (OOI), which will potentially provide significant infrastructure in support of ocean climate observation, beginning in FY 2006. The ongoing NSF-NOAA cooperative project for CLIVAR-carbon ocean surveys has proved to be an interagency-international-interdisciplinary success. ONR maintains a GODAE data server at Monterey that needs to be sustained after the experiment period (2003-2007) as permanent international infrastructure. The UNOLS fleet provides ship support for ocean operations. NASA's development of remote sensing techniques is key.

Focus of the Program:
- Extending the *in situ* networks to achieve global coverage – moored and drifting buoys, profiling floats, tide gauges stations, and repeated ship lines. The networks are illustrated in Figure 1.
- Building associated data and assimilation subsystems.
- Building observing system management and product delivery infrastructure.

Linkage to NOAA strategic goals:
- NOAA's Mission Goal 2 – "Understand climate variability and change to enhance society's ability to plan and respond."

- NOAA Strategy – Monitor and Observe: “We will invest in high-quality, long-term climate observations and will encourage other national and international investments to provide a comprehensive observing system in support of climate assessments and forecasts.”

Intended program outcomes and performance measures:

- Outcome -- A sustained global system of complementary *in situ*, satellite, data, and modeling subsystems adequate to accurately document the state of the ocean and force climate models.
- Performance Measures:
    - Reduce the error in global measurement of sea surface temperature.
    - Reduce the error in global measurement of sea level change
    - Reduce the error in global measurement of ocean carbon sources and sinks
    - Reduce the error in global measurement of ocean heat content and transport

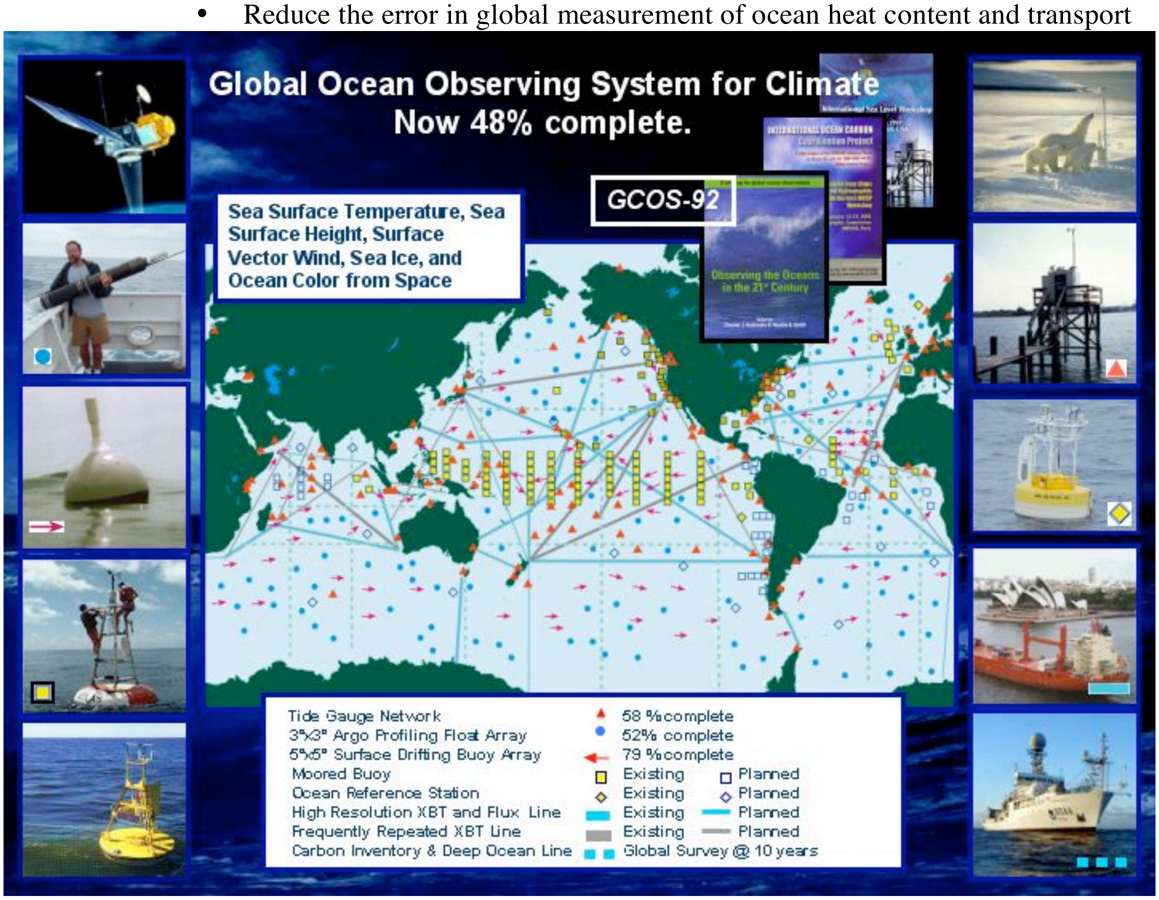

Figure 1

Schedule and milestones: “FY 2006 Current Program” contained in the Climate Goal Program Plan.

Year	2003	2004	2005	2006	2007	2008	2009	2010
System % complete:	45	48	53	55	63	65	68	73

Communications plan for providing information to decision makers (government and non-government):

The observing system delivers the “up front” information to the forecast centers, research programs, and assessments. In the past, the program has depended largely on these partner

Climate Program Components to develop and deliver information products that are user-friendly for management and policy decisions. During FY 2003, however, the need was identified for the program to begin addressing the development of climate data records and analyses as first order products in addition to depending on the forecast, research, and assessment partners for climate product delivery. In 2004, the OCO produced the first *Annual Report on the State of the Ocean and the Ocean Observing System for Climate*. This first report for the fiscal year 2003 was a demonstration project; it proved highly successful; the project will be continued documenting the state of the ocean and reporting on observing system progress annually. The annual reports include sections targeted for three audiences: 1) decision-makers and non-scientist, 2) scientists, 3) observing system managers.

How implementation is being accomplished:
The "Networks" are managed by 19 distributed centers of expertise at the NOAA Labs, Centers, Joint Institutes, universities and business partners. The "System" is centrally managed at the Office of Climate Observation (OCO), a project office within the NOAA Climate Program Office.

Where it is being done (lab, university, joint institute):
AOML, PMEL, ETL, JIMAR (University of Hawaii), JIMO (Scripps Institution of Oceanography), CICOR (Woods Hole Oceanographic Institution), JISAO (University of Washington), CIMAS (University of Miami), CICAR (Columbia University), NCDC, NODC, CO-OPS, AMC, PMC, NDBC, NCEP, FSU (Florida State University), SAI (Service Argos Inc.) and OCO.

By whom (detail on number and type of personnel involved):
- 45 Federal FTEs
- 103 non-Federal FTEs
- 2 Contract FTEs and 1 Federal seconded FTE at international coordination offices

Customers, NOAA and non-NOAA, served:
- Operational forecast centers (e.g., NCEP, ECMWF, BoM, JMA)
- International research programs (e.g., CLIVAR, GEWEX, ASOF)
- Major scientific assessments – national and international (e.g., IPCC)

Potential benefits:
The Nations of the world will have the quantitative information necessary to: 1) forecast and assess climate variability and change, and 2) effectively plan for and manage their response to climate change.

FY 2004 Accomplishments:
Incremental advances were accomplished across all of the networks. These advancements are documented in the individual progress reports that follow. The ocean system overall advanced from 45% complete in FY 2003 to 48% complete in FY 2004.

The new Office of Climate Observation (OCO) was officially opened at 1100 Wayne Avenue, Silver Spring, on April 14, 2004. Seven personnel were assigned to the OCO, six in Silver Spring and one detailed to the IOC at UNESCO in Paris to serve on the JCOMM secretariat. The OCO staff consists of three Federal employees, one IPA scientist, two contracted technical experts, and one program management intern detailed to the OCO from JAMSTEC. The OCO management plan provides for development of system-wide services to:

- Monitor the status of the globally distributed networks; report system statistics and metrics routinely and on demand.
- Evaluate the effectiveness of the system; recommend improvements.
- Advance the multi-year Program Plan; evolve the *in situ* networks through directed funding;
- Focus intra-agency, interagency, and international coordination.
- Organize external review and user feedback.
- Produce annual reports on the state of the ocean and the adequacy of the observing system for climate.

The second Annual System Review was conducted April 13-15 in Silver Spring. This meeting brought together project managers to discuss system-wide issues and engage in program strategic planning. It also provided the annually scheduled forum for observing system users to provide feedback and discuss their requirements and recommendations for system evolution with the project managers. Review of the NDBC and PMEL plan for transition of TAO operations from PMEL to NDBC was a major topic of discussion during the 2004 Annual Review. The issue of the gap in delivery of ocean analyses as an end product of ocean observations was also a major part of the strategic discussions. The Climate Observation Program in FY 2005 will begin a program of ocean analysis work to ensure that this gap gets filled.

During the Annual System Review, the OCO sponsored an external review of the NDBC/PMEL TAO Transition Planning. The review panel consisted of the Climate Observing System Council (COSC) members plus invited experts including international partners from JAMSTEC and the IOC. As a result of the review the Transition Plan was modified to address recommendations of the panel and then a second quick turn around review of the modified plan was conducted by the COSC in September before the plan was presented to NOAA management for approval.

In cooperation with the international GCOS program office in Geneva, the OCO developed a special web page in support of the GCOS *Implementation Plan for the Global Observing System for Climate in Support of the UNFCC*C (GCOS-92). The OCO web page, www.oco.noaa.gov/page_status_reports_global.jsp, provides up-to date global maps and summary statistics from JCOMMOPS and other observing system partners contributing to international implementation of GCOS-92.

A demonstration project was initiated at OCO in cooperation with the GOOS Program Office at UNESCO and JCOMMOPS in Toulouse, to routinely report on progress of the observing system and contributions by countries. A consolidated report is now available on the OCO web site, accessible via the international portal at www.jcommops.org/network_status, which lists the 64 countries and the European Union that maintain elements of the composite ocean observing system and the number platforms and expendables contributed by each country. It is the intent of the OCO to develop a routine to update this report quarterly. This report allows tracking of progress toward international implementation of the ocean system specified in GCOS-92.

Table 3.1. This table provides names of PIs (in alphabetical order), the title of their funded projects, and websites linked with their projects.

Office of Climate Observation – 2004 Funded Projects		
Principal Investigator/ Co-Principal Investigator(s)	**i. ii. Title of Project**	**Project Website**
Baringer, Molly Goni, Gustavo Garzoli, Silvia	Atlantic High Density XBT Lines	http://www.aoml.noaa.gov/phod/hdenxbt/
Baringer, Molly Johns, Elizabeth Meinen, Christopher Garzoli, Silvia	Western Boundary Time Series in the Atlantic Ocean	http://www.aoml.noaa.gov/phod/floridacurrent/
Bernard, Landry	The Tropical Atmosphere Ocean (TAO) Array	http://www.pmel.noaa.gov/tao/
Cook, Steven Molinari, Robert	ENSO Observing System, XBT component	http://seas.amverseas.noaa.gov/seas/goosplots.html Associated projects: http://ww.jcommops.org http://seas.amverseas.noaa.gov/seas http://www-hrx.ucsd.edu http://www.cmdl.noaa.gov http://www://sahfos.org http://www.aoml.noaa.gov/phod/benchmarks/index.html
Consortium on the Ocean's Role in Climate (CORC)		
Cayan, Daniel	1. CORC: Surface Fluxes and Analysis	Data distributed by: ftp://tenaya.ucsd.edu/pub
Cornuelle, Bruce Stammer, Detlef Miller, Art	2. CORC: Four-Dimensional Variational (4DVAR) Data Assimilation in the Tropical Pacific	
Davis, Russ	3. CORC: Underwater Gliders for Monitoring Ocean Climate	www.Spray.UCSD.edu
Niiler, Pearn	4. CORC: Drifter Observations	
Roemmich, Dean	5. CORC: High Resolution XBT/XCTD (HRX) Transects	http://www-hrx.ucsd.edu
Rudnick, Daniel	6. CORC: Development of an Underway CTD	
Schmitt, Ray	7. CORC: Lagrangian Salinity Profiling: Evaluation of Sensor Performance	

Weller, Robert Bahr, Frank Hosom, David	8. CORC: Observations of Air-Sea Fluxes and the Surface of the Ocean	http://uop.whoi.edu/vos/ http://frodo.whoi.edu ftp.whoi.edu/pub/users/fbahr/VOS
Cronin, Meghan Meinig, Christian Sabine, Christopher	Flux Mooring for the North Pacific's Western Boundary Current: Kuroshio Extension Observatory (KEO)	http://www.pmel.noaa.gov/keo
Fairall, Chris	High Resolution Climate Data from Research and Volunteer Observing Ships	http://www.etl.noaa.gov/et6/air-sea/
Feely, Richard Wanninkhof, Rik Sabine, Chris Johnson, Gregory Baringer, Molly Bullister, John Mordy, Calvin Zhang, Jia-Zhong	Global Repeat Hydrographic/CO_2/Tracer Surveys in Support of CLIVAR and Global Carbon Cycle Objectives: Carbon Inventories and Fluxes	
Garzoli, Silvia Molinari, Robert	Surface Drifter Program	www.aoml.noaa.gov/phod/dac/ http://www.aoml.noaa.gov/phod/trinanes/java.html
Gill, Stephen Zervas, Chris	National Water Level Program Support Towards Building a Sustained Ocean Observing System for Climate	http://tidesandcurrents.noaa.gov http://www.co-ops.nos.noaa.gov/sltrends/sltrends.shtml
Hankin, Steve Feely, Dick Kozyr, Alex Peng, Tsung-Hung	An End-to-End Data Management System for Ocean pCO_2 Measurements	http://cdiac3.ornl.gov/underway/servlets/dataset http://mercury.ornl.gov/ocean/ http://www.ferret.noaa.gov/Ferret/LAS/CDIAC_LAS/
Harrison, Ed	Observing System Research Studies	
Kermond, John	Teachers at Sea	www.tas.noaa.gov
Kern, Kevin Hankin, Steve	Progress Report for the Observing System Monitoring Center (OSMC)	http://osmc.noaa.gov/OSMC/
McPhaden, Michael	An Indian Ocean Moored Buoy Array for Climate	ftp://ftp.marine.csiro.au/pub/meyers/Implementation%20Plan/
McPhaden, Michael	Pilot Research Moored Array in the Tropical Atlantic (PIRATA)	http://www.pmel.noaa.gov/pirata/ http://www.pmel.noaa.gov/tao/
Merrifield, Mark	The University of Hawaii Sea Level Center	http://uhslc.soest.hawaii.edu
Miller, Laury	Satellite Altimetry	http://ibis.grdl.noaa.gov/SAT/
Niiler, Peter	The Global Drifter Program	
O'Brien, James Smith, Shawn Bourassa, Mark	Climate Variability in Ocean Surface Turbulent Fluxes	http://www.coaps.fsu.edu/RVSMDC/SAC http://www.coaps.fsu.edu/RVSMDC/SAC/index.shtml

O'Brien, James Smith, Shawn Bourassa, Mark	U.S. Research Vessel Surface Meteorology Data Assembly Center	http://www.coaps.fsu.edu/RVSMDC/
Reynolds, Richard	*In situ* and Satellite Sea Surface Temperature (SST) Analyses	http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/
Richter-Menge, Jackie	Monitoring Ice Thickness in the Western Arctic Ocean	http://www.crrel.usace.army.mil/sid/IMB/
Rigor, Ignatius	Monitoring Eurasian Basin of the Arctic Ocean	http://iabp.apl.washington.edu/
Sabine, Chris Chavez, Francisco	High-Resolution Ocean and Atmosphere pCO_2 Time-Series Measurements	http://www.pmel.noaa.gov/co2/moorings/
Wanninkhof, Rik Feely, Richard Bates, Nicholas Millero, Frank Takahashi, Taro Cook, Steven	Document Ocean Carbon Sources and Sinks: Initial Steps Towards a Global Surface Water pCO_2 Observing System; Underway CO_2 Measurements on the NOAA ships Ka'imimoana and Ronald H. Brown and RVIB Palmer and Explorer of the Seas	http://www.aoml.noaa.gov/ocd/gcc http://www.pmel.noaa.gov/co2/uwpco2/ http://www.ldeo.columbia.edu/res/pi/CO2/
Weller, Robert Plueddemann, Albert	Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS)	WHOI: https://www.whoi.edu UOP Group: http://uop.whoi.edu Stratus Project: http://uop.whoi.edu/stratus NTAS Project: http://uop.whoi.edu/ntas WHOTS Project: http://uop.whoi.edu/hawaii
Weller, Robert Bahr, Frank Hosom, David	Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic (Atlantic VOS)	http://frodo.whoi.edu http://uop.whoi.edu/vos/

3.1a. Atlantic High Density XBT Lines

by Molly Baringer, Gustavo Goni and Silvia Garzoli

PROJECT SUMMARY

This program is designed to measure the upper ocean thermal structure in key regions of the Atlantic Ocean (Figure 1). The seasonal to interannual variability in upper ocean heat content and transport is monitored to understand how the ocean responds to changes in atmospheric and oceanic conditions and how the ocean response may feedback to the important climate fluctuations such as the NAO. This increased understanding is crucial to improving climate prediction models. Within this context, five XBT lines have been chosen to monitor properties in the upper layers of the Atlantic Ocean. The continuation of AX07 and AX10 and the implementation of AX08 and AX18 were recommended at the Meeting of the Ocean Observing System for Climate held in St. Raphael in 1999.

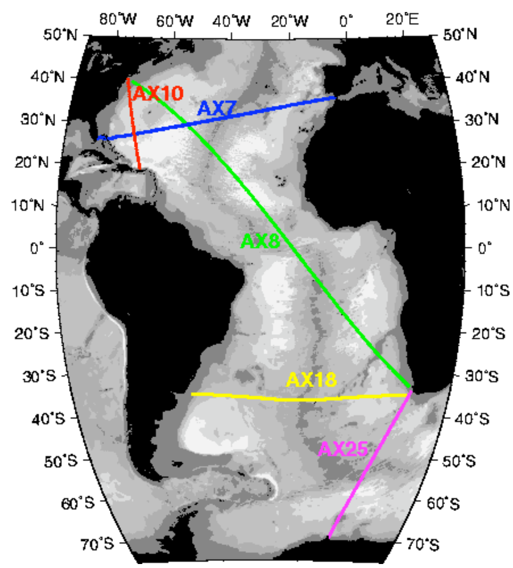

Figure 1. Location of high density XBT lines AX07, AX08, AX10, AX18, and AX25.

The high-density line AX07 is located nominally along 30°N extending from the Straits of Gibraltar in the eastern Atlantic to the east coast of the United States at Miami, Florida. This latitude is ideal for monitoring heat flux variability in the Atlantic because it lies near the center of the subtropical gyre, which has been shown to be the latitude of the maximum poleward heat flux in the Atlantic Ocean.

The high-density line AX10 is located between the New York City and Puerto Rico. This line closes off the United States eastern seaboard, where subtropical temperature anomalies could have the greatest interaction with the atmosphere. This line was chosen to monitor the location of the Gulf Stream and its link to the NAO.

The high-density line AX08, part of the Tropical Atlantic Observing System, crosses the tropical Atlantic in a NW-SE direction between North America and South Africa. Historical data along AX08 and other historical temperature observations in the tropics exhibit decadal and multi-decadal signals. It has been hypothesized that this large time scale signal may cause atmospheric variability. Given the importance of the tropical Atlantic in climate variability, and the scarcity of observations in this region, data obtained from the measurements along this line are key to improve our understanding of the ocean and ability of climate forecast. Temperature profiles obtained from this line will help to monitor the main zonal currents and undercurrents in the tropical Atlantic and to investigate their spatial and temporal variability.

The high-density XBT line AX18, which runs between Cape Town and South America (Montevideo, Uruguay, or Buenos Aires, Argentina) is geared towards improving the current climate observing system in the South Atlantic, a region of poor data coverage. The main objective of this line is to monitor the meridional mass and heat transport in the upper 800 m across 30S. Given the importance of the South Atlantic and the scarcity of observations in this region, data obtained from the measurements along this line will be used to investigate the role of the South Atlantic in improving climate forecasts.

The AX25 line was implemented to measure changes in the variability in the upper layer interocean exchanges between South Africa and Antarctica on seasonal and interannual time scales. In addition, by exploiting the relationship between upper ocean temperature and dynamic height, XBTs can be used to infer velocities even in the Southern Ocean where salinity changes are important. In this way XBT sections can be used to measure changes in oceanic heat transport.

The global atmospheric and oceanic data from Ships of Opportunity (SOOP) have been the foundation for understanding long-term changes in marine climate. This program is a direct component of the NOAA's Program Plan for building a sustained Ocean Observing System for Climate and directly addresses one of its *milestones:*

- Occupy 41 volunteer observing ship (VOS) lines for high accuracy upper ocean and surface meteorological observations, by 2007 (Figure 2).

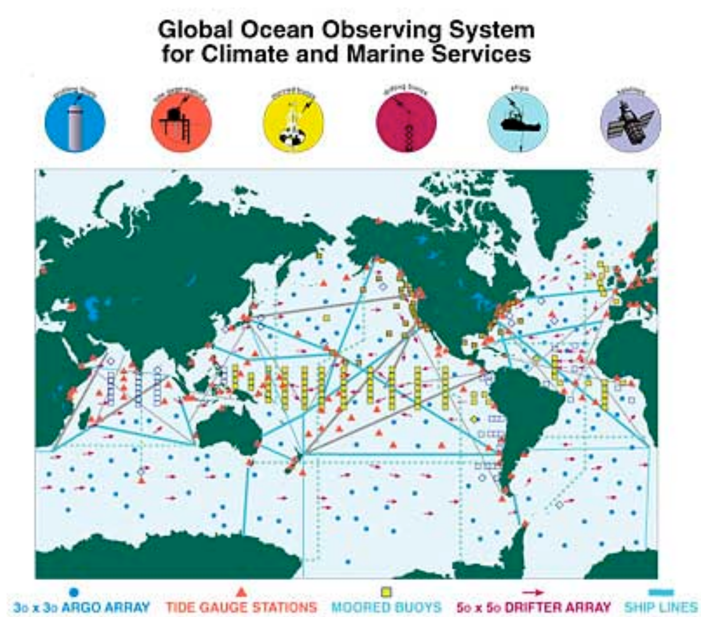

Figure 2. NOAA's Global Observing System for Climate.

The Global Ocean Observing System (GOOS) Center and its integral components, the Global Drifter Program (GDP) and Voluntary Observing Ship (VOS) XBT Program are both participating members of JCOMM and JCOMMOPS. The VOS XBT program is represented annually at the WMO/IOC Ship Observations Team (SOT) meeting. AOML presently Chair the Ship of Opportunity Implementation Panel (SOOPIP).

Responsible institutions:
NOAA/AOML is solely responsible for managing all aspects of this project. International partners collaborate in maintaining these lines: The Hydrographic Naval Office (SHN) of Argentina, the University of Cape Town, and the South African Weather Service are currently collaborating with this program.

Project web site:
http://www.aoml.noaa.gov/phod/hdenxbt/

Interagency and international partnerships:
Several agencies are currently collaborating with this project. The Argentine Hydrographic Office (SHN) provides the personnel to deploy the XBTs in AX18. The South African Meteorological Service is our contact in Cape Town and Durban to store the equipment in between transects and to provide ship riders.

Relation to the Ten Climate Monitoring Principles:
High-density line AX07 and AX10 have been maintained since 1994 and 1996, respectively, providing a homogeneous data set for almost a decade. Sustained observations from these and the other two high-density lines are required to have observations with adequate spatial and temporal resolution for climate studies. High-density observations in AX08, AX18, and AX25 provide data in poorly surveyed regions. Data are of easy access, interpretation and visualization. AOML has the facilities, personnel and infrastructure to maintain a stable, long-term commitment to these observations.

FY 2004 PROGRESS

Instrument/platform acquisitions for FY2004 and locations where XBTs were deployed:

Line	Number XBTs launched
AX07	1173(1)
AX08	1189(2)
AX10	425
AX18	725(3)
AX25	188

(1) Includes 143 XBTs deployed during September 2003, which were not included in last year's report. (2) Includes an estimate number of 300 XBTs from a recently finished transect that has not been processed yet. (3) Includes an estimate number of 180 XBTs from an underway transect.

The exact locations of XBT deployments are shown on the web page corresponding to each line (Figure 3).

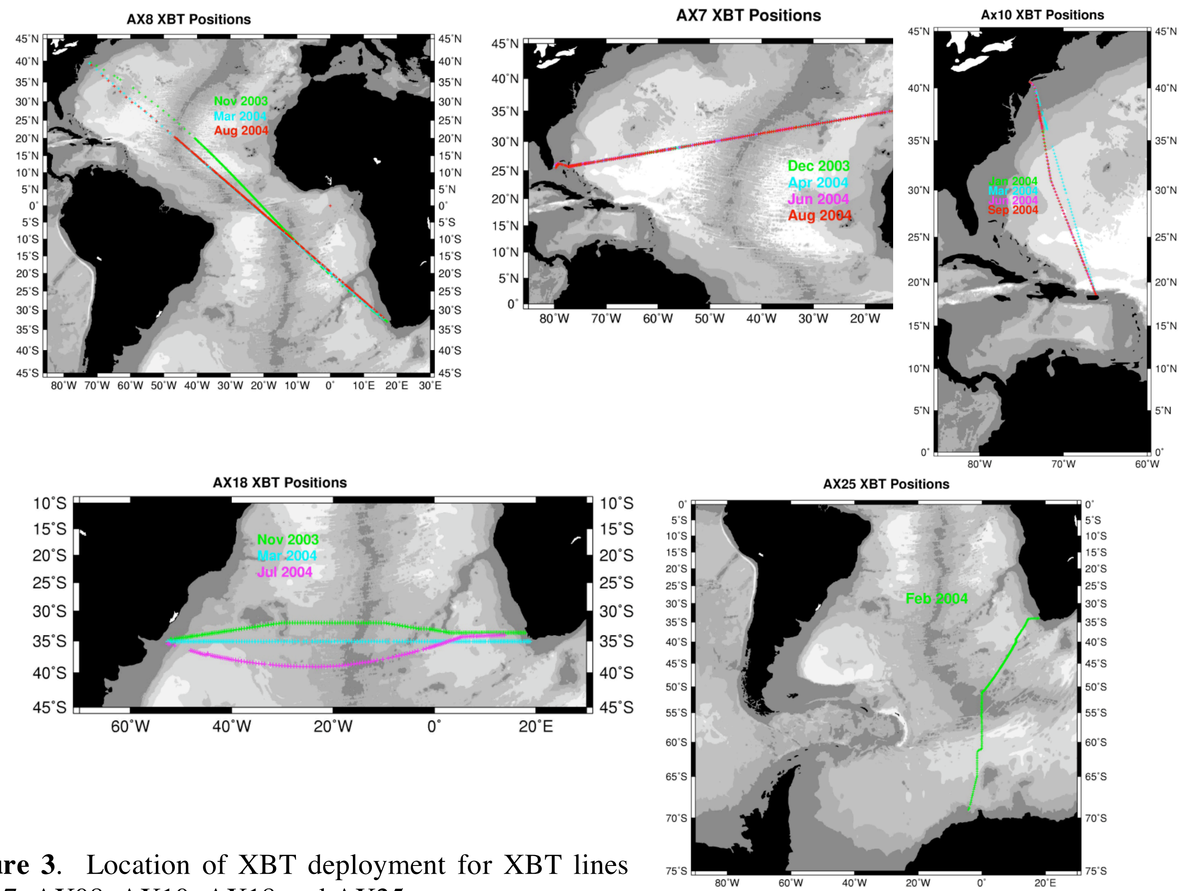

Figure 3. Location of XBT deployment for XBT lines AX07, AX08, AX10, AX18 and AX25

Data:
The temperature profiles specifications include depths from 0 to 750 m., although sometimes temperatures can be recorded as deep as 800 m. Data are stored on the computer system on the ships on which we have installed Shipboard Environmental data Acquisition (SEAS) Systems. The real-time data are transmitted via Standard C and are distributed on the GTS and the delayed mode or full resolution data are stored at the National Oceanographic Data Center (NODC). Data are also kept at AOML and provided through a web page approximately two weeks after each transect is finished.

Project Costs:
Please refer to the Proposed Budgets for information on anticipated and unanticipated project costs.

Ships of Opportunity:
These transects are occupied by *ships of opportunity*. The AX07, AX08, AX10, AX18, and AX25 transects last, in average, approximately 10, 17, 3, 11, and 15 days. We also provide information to them on how the data obtained from these high density cruises are used to improve weather and climate forecast.

The search for ships of opportunity remains an issue as ships constantly change routes. A major effort is required to contact Shipping Lines that cover the transects. The coordination necessary among multiple groups using ship facilities is handled by high-density personnel.

Research Highlights:
High density XBT data allows us to compute statistical information about the independent spatial scales that is necessary for data assimilation and mapping. Below is an example (Figure 4) of the decorrelation length scale determined along AX07 indicating that the spatial scales are depth dependent.

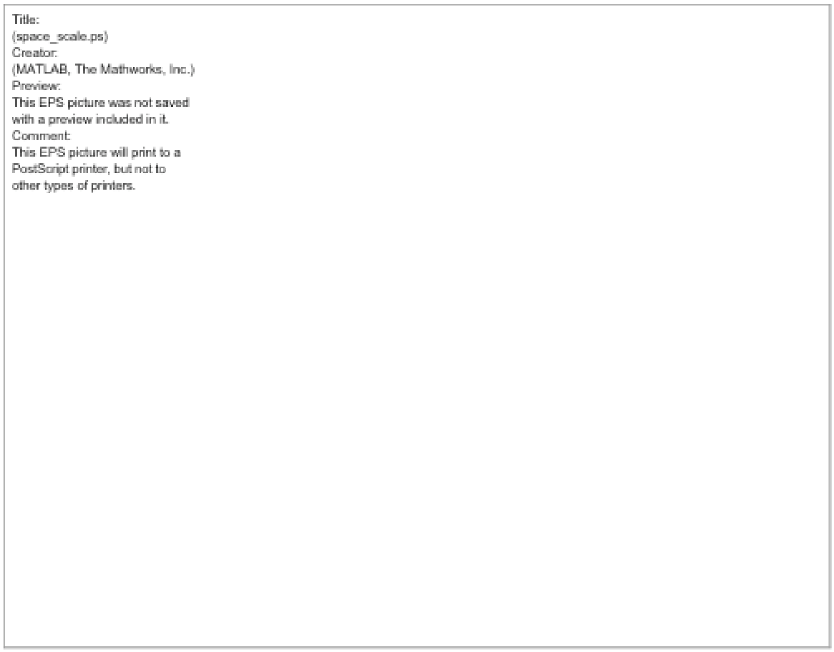

Figure 4. Decorrelation length scale (in km) as a function of depth for AX07. The solid line is the mean and the dotted line is the standard deviation.

The long time series available along some of the high density XBT lines allows us to examine decadal trends in subsurface (and surface) temperature anomalies. Below we show an example from AX10 of the temperature anomalies at 150 meters smoothed using a three-year running mean (Figure 5).

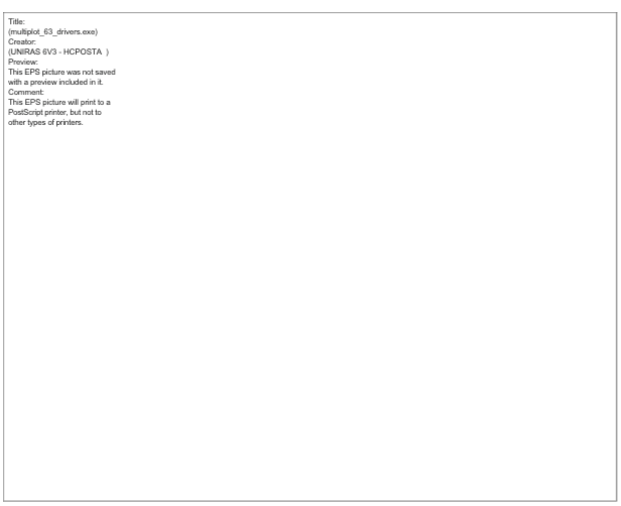

Figure 5. Sea surface temperature anomalies along AX10 showing a long time (decadal) signal.

Temperature sections from the AX08 transect are used to investigate the location, geostrophic transport and their variability of the main zonal upper ocean currents in the tropical Atlantic (Table 1).

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Preview:
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with a preview included in it.
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PostScript printer, but not to
other types of printers.

Table 1. Upper ocean currents in the tropical Atlantic during the first three AX08 transects.

Data from the AX18 transect is currently being used to estimate the transport of the major western boundary currents (Brazil and Agulhas) and of rings shed by these current systems (Figure 6). These values are being compared with altimeter-based estimates.

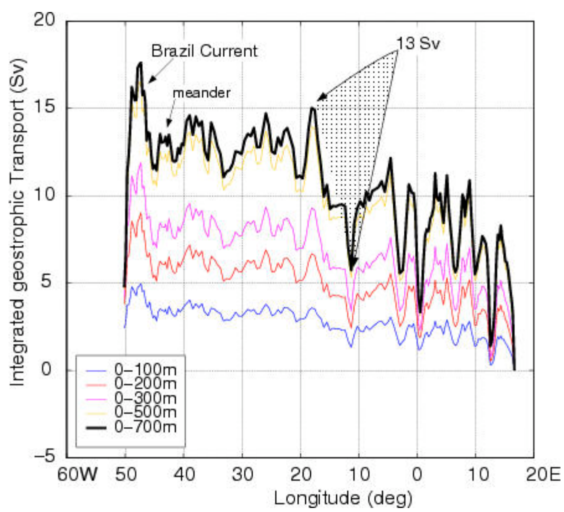


Figure 6. (a) The integrated water mass transport from west to east is computed for the July 2002 AX18 transect. The contribution from 5 layers from the surface to 100, 200, 300, 500, and 700 m relative to a zero flow at 800 m are shown.

3.2a. Western Boundary Time Series in the Atlantic Ocean

Project Managers: Molly Baringer and Silvia Garzoli
Scientists Involved: Molly Baringer, Christopher Meinen, Silvia Garzoli, and Elizabeth Johns

PROJECT SUMMARY

This program is included in one of the eleven components of the NOAA Global Ocean Observing System: Ocean reference stations. This project consists of two components to monitor the western boundary currents in the subtropical Atlantic: *Task 1:* Florida Current transport measurements using a submarine telephone cable plus calibration cruises, *Task 2:* Deep Western Boundary Current transport and property measurements using dedicated research ship time and moored instruments.

Scientific Rationale:

In the subtropical North Atlantic, the meridional overturning circulation consists primarily of two western boundary components: the northward flowing Gulf Stream and the southward flowing Deep Western Boundary Current. The Gulf Stream is the strong surface intensified flow along the east coast of the United States that brings warm waters of tropical origin northward along the eastern seaboard of the United States. The Gulf Stream also brings with it carbon, nutrients and tropical fish. It supplies warm waters along the coast that impact a multitude of important climate phenomena including hurricane intensification, winter storm formation and moderate European weather. The Gulf Stream includes the bulk of what we call the upper limb of the thermohaline circulation in the subtropical Atlantic, in addition to a strong wind-driven flow. As the Gulf Stream flows northward, it loses heat to the atmosphere until eventually in the subpolar North Atlantic some of it becomes cold enough to sink to the bottom of the ocean. This cold deep water then returns southward along the continental slope of the eastern United States as the Deep Western Boundary Current, continuing the circuit of the overturning circulation.

Off the coast of Florida, the Gulf Stream is referred to as the Florida Current and is fortuitously confined within the limited geographic channel between Florida and the Bahamas Islands, thus making a long-term observing system cost effective and sustainable. Similarly, the Deep Western Boundary Current is located within several hundred miles to the east of the Abaco Island, Grand Bahamas. The convenient geometry of the Bahamas Island chain thus allows an effective choke point for establishing a long term monitoring program of this deep limb of the overturning circulation.

Task 1: Transport of the Florida Current

This project maintains NOAA's well-established and climatically significant Florida Current volume transport time series. Over 20 years of daily mean voltage-derived transports have been obtained for the Florida Current using out-of-service and in-use cables spanning the Straits of Florida. The cable voltages can be converted to physically meaningful transport estimates, i.e. intensity of the flow, using electromagnetic induction theory and data from calibration sections. These transport measurements contain decadal changes on the order of 10-25% of the long-term mean transport and these decadal changes track the North Atlantic Oscillation Index. The strong correlation of Florida Current transport variability with the North Atlantic Oscillation by extension indicates a correlation with the large-scale sea-surface temperature patterns associated with the North Atlantic Oscillation. This suggests connections to tropical Atlantic variability on climatically significant time scales, and links with the numerous socially significant weather and climate phenomena that are thought to be related through large scale ocean-atmosphere patterns in the Atlantic, including decadal and interdecadal variations in fisheries, rainfall, and hurricane activity.

Funding provides for continuous collection of cable voltages (every minute) and automated processing of simple geomagnetic corrections. In addition to the cable measurements, quarterly calibration cruises are required for this project's success. These measurements complement a related project that measures the upper ocean thermal structure in the Atlantic through high-density VOS XBT observations. Funding provides for four two-day small charter boat calibration cruises on the R/V F. G. WALTON SMITH each year.

Task 2: Deep Western Boundary Current Time Series

Over the past 20 years a variety of snapshot sections and time series moorings have been placed along the continental slope east of Abaco Island, Grand Bahamas, in order to monitor variability of the transport carried by the Deep Western Boundary Current. The Abaco time series began in August 1984 when the NOAA Subtropical Atlantic Climate Studies Program extended its Straits of Florida program to include measurements of western boundary current transports and water mass properties east of Abaco Island, Grand Bahamas. Since 1986, over 20 hydrographic sections have been completed east of Abaco, most including direct velocity observations, and salinity and oxygen bottle samples. Many sections have also included carbon, chloroflourocarbon, and other tracers.

The repeated hydrographic and tracer sampling at Abaco has established a high-temporal-resolution record of water mass properties in the Deep Western Boundary Current at 26°N. Events such as the intense convection period in the Labrador Sea and the renewal of classical Labrador Sea Water in the 1980's are clearly reflected in the cooling and freshening of the Deep Western Boundary Current waters off Abaco, and the arrival of a strong chlorofluorocarbon pulse approximately 10 years later. This data set is unique in that it is not just a single time series site but a transport section, of which very few are available in the ocean that approach a decade in length.

This task includes annual cruises across the DWBC to measure the water mass properties and transports and seeks to develop a cost effective method for long-term continuous monitoring of this flow. In a previous test project, from October 1995 to June 1997 three Inverted Echo Sounders (IES) were deployed adjacent to the sites of current meter moorings deployed by scientists from RSMAS/UM (Johns et al. 2004). The objective of the IES deployments was to study the possibility of establishing a low cost monitoring system to replace the current meter moorings and to extrapolate the hydrographic data over the spans between cruises. Analysis of the data (Meinen et al. 2004), demonstrated that through a combination of IES, pressure gauges and hydrographic data, the DWBC transport and the Antilles Current can be accurately monitored. Based on these results, 3 PIES (PIES: IESs additionally equipped with bottom pressure gauges) funded by OCO (one also equipped with a current meter, a C-PIES) were deployed along the Abaco line. These instruments are designed so that the data can be collected via acoustic telemetry from a passing ship without recovering the instruments. It is expected that the data will be collected every 6 to 12 months, depending on the number of cruises. In addition to the PIES funded by OCO, 2 additional instruments (one IES and 1 PIES) were deployed. These instruments do not have the acoustic telemetry capability; funding permitting the instruments may be upgraded in the future. This project is part of an interagency and international partnership, RAPID/MOCHA, and over the next four years the combination of RAPID/MOCHA along with the NOAA funded WBTS project will allow us to visit our new moorings sites twice each year.

These continued time series observations at Abaco are seen as serving three main purposes for climate variability studies:

- Monitoring of the DWBC for water mass and transport signatures related to changes in the strengths and regions of high latitude water mass formation in the North Atlantic for the ultimate purpose of assessing rapid climate change.
- Serving as a western boundary endpoint of an international subtropical meridional overturning circulation (MOC)/heat flux monitoring system designed to measure the interior dynamic height difference across the entire Atlantic basin and its associated baroclinic heat transport.
- Monitoring the intensity of the Antilles Current as an index (together with the Florida Current) of interannual variability in the strength of the subtropical gyre.

How this project addresses NOAA's Program Plan for *Building a Sustained Ocean Observing System for Climate*:

The program plan for "Building a Sustained Ocean Observing System for Climate" includes the objectives of:

1) Documenting the heat uptake, transport, and release by the ocean; and
2) Documenting the air-sea exchange of water and the ocean's overturning circulation.

This project is one component of the "Ocean Reference Station" at approximately 26ºN in the Atlantic Ocean that specifically addresses these goals by providing long-term measures of two components of the global thermohaline (overturning) circulation. Long-term monitoring of key choke points, such as the boundary currents along the continents including the Gulf Stream and the Deep Western Boundary Current, will provide a measurement of the primary routes of ocean heat, and mass transport and hence include the bulk of the Meridional Overturning Circulation.

How this project is managed in cooperation with the international implementation panels, in particular the JCOMM panels:

This program is managed under the AOML Global Ocean Observing System (GOOS) Center, created in cooperation with national and international steering committees to provide an administrative umbrella that coordinates several operational oceanographic data collection networks. As part of GOOS, this program falls within the Observations Program Area of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) where the AOML GOOS center is a participant.

Responsible institutions for all aspects of project:

NOAA/AOML is responsible for this project.

Project web site URL and pertinent web sites for your project and associated projects:

http://www.aoml.noaa.gov/phod/floridacurrent/

Interagency and international partnerships:

This project provides the cornerstone observations required for a national and international pilot program to develop an observing system to monitor the intensity and heat transport of the overturning circulation at 26ºN in the Atlantic. NOAA provides the essential Florida Current component of the monitoring system, direct hydrographic observations of the DWBC and its history since 1984 east of Abaco Island, Grand Bahamas, repeated high density lines at a nearby latitude, plus ship time that doubles the temporal sampling for both programs. Partners in this project include the National Science Foundation sponsored Meridional Overturning, Circulation and Heat transport Array (MOCHA) proposal to the University of Miami, the United Kingdom's National Environmental Research Council (NERC) sponsored Rapid Climate Change Program proposal to the University of Southampton (England) and the Woods Hole Oceanographic Institution.

Project management and the Ten Climate Monitoring Principles:
This program is managed in accordance with the Ten Climate Monitoring Principles (Program Plan, Mike Johnson 2003). This time series contains several gaps in the continuous record due to logistical requirements, funding shortfalls and, more recently, to instrument failure. To assure an adequate climate record, parallel testing and parallel measurements would be required to assure continuity of the time series without gaps. 'Data quality and continuity', principle 4 of the ten climate monitoring principles, and 'data and metadata access', principle 10, have suffered as a direct result. We request additional funds in "*Budget Justification*" to address these deficiencies and assure a better research quality time series.

FY 2004 PROGRESS

Instrument/platform acquisitions for fiscal year and where equipment was deployed:

Task 1: Continuous transport of the Florida Current
Recording instruments are located at Eight Mile Rock, Grand Bahamas Island. At Eight Mile Rock and in West Palm Beach, Florida, electrode equipment is in place, securing a stable reference voltage (i.e. grounds) at either end of the submerged telephone cable owned by AT&T. The monitored cable can be seen in Figure 1, stretching across the Florida Straits. Data acquisition has continued without incident until August 31, 2004 when Hurricane Frances and then Hurricane Jeanne substantially damaged infrastructure to the Bahamas including telephone service and electricity. The building with the recording equipment lost its roof and the equipment appears to have been shorted out by excess water. As a result of this dramatic occurrence, some data are likely to be unrecoverable. An upcoming trip to the Bahamas will ascertain the extent of the damage. This FY has seen considerable progress in quality control of the calibration section data and the cable transport data including de-tiding cable transports and section data and preliminary analysis of geomagnetic signal removal. Cable voltages are recorded every

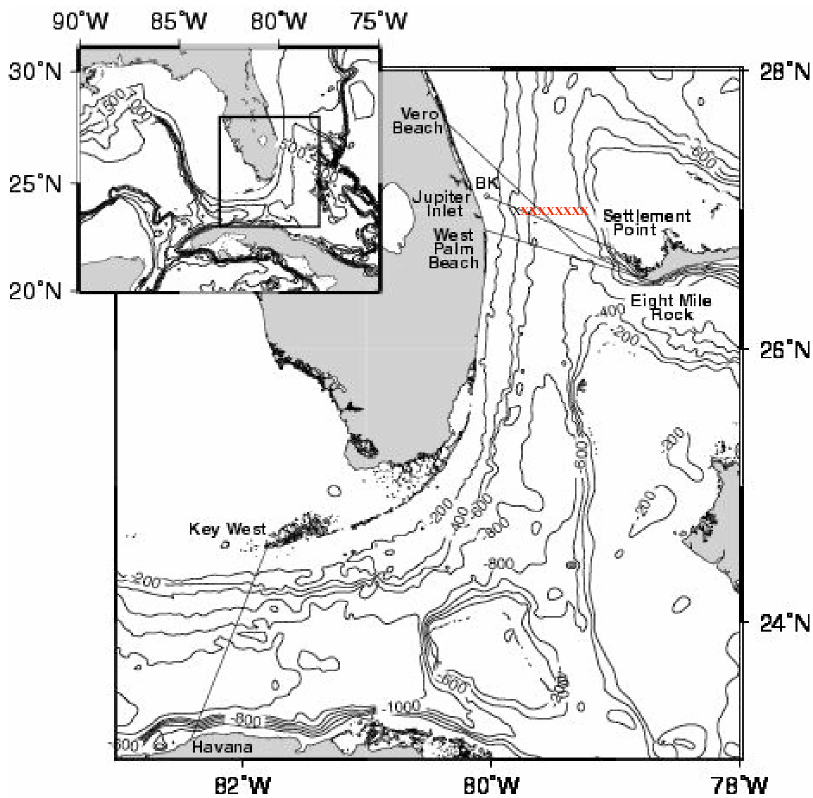


Figure 1: Location of submarine telephone cables (solid black) and nine stations (red) occupied during calibration cruises.

minute, hourly averaged and post processed to form daily transport estimate. The Table 1 below shows the number of hourly averaged voltage measurements.

FY 2004	FY 2003	FY 2002
7632 Hours 87% Return	7755 Hours 89% Return	6264 Hours 72% Return[1]

Table 1: Data return from continuous cable voltages (% Return based on the maximum number of hours possible in one year: e.g. 8760 for non-leap years and 8784 for leap years like 2004).

Planned Cruise	FY 2004	FY 2003	FY 2002
1	9-Dec-2003	- clearance problems	- weather problems
2	16-Dec-2003	- clearance problems	Dec 14, 2001
3	9-Jan-2004	- equipment problems	Mar 12, 2002
4	13-Jan-2004 – GPS failure on two stations	18-Mar-03	Mar 18, 2002
5	7-May-2004	June 7, 2003 – dropsonde failure	June 3, 2002
6	24-May-2004	- no dropsonde	June 6, 2002
7	Jun 7, 2004	- no dropsonde	Aug 23, 2002 – dropsonde lost
8	Jun 11, 2004	- no dropsonde	
9	Aug 24, 2004		
10	1-Sep-2004 - GPS antenna failure		
	80% successful[2]	13% successful[3]	63% successful

Table 2: Cruise dates for 1-day small boat calibration cruises using dropsonde instrument.

Small charter boat calibration trips

A total of ten 1-day surveys were conducted using a dropsonde profiler. Typically eight cruises are scheduled per year, but additional cruises were carried out this year due to scheduling and equipment problems from last FY. Measurements are taken at nine stations (shown in Figure 1) and include vertically averaged horizontal velocity, surface velocity and expendable temperature probes (XBTs). The cruise dates are shown in Table 2.

New equipment was purchased by AOML base funds this FY to build a new dropsonde after the loss of the previous dropsonde on August 23, 2002. The new purchases included a self-recording conductivity, temperature depth (CTD) recorder, GPS, radio transmitter, glass pressure housing, batteries and antennae.

[1] Note old recording system failed in FY 2002.
[2] Two additional cruises were planned for FY04 due to dropsonde failures in FY03.
[3] Sections missing due to: dropsonde failure (4) and clearance problems (2).

Full Water Column calibration cruises:
Four 2-day cruises on RV Walton Smith were conducted. All cruises include nine stations with full water column CTD, lowered ADCP, and continuous shipboard ADCP. The station locations are the same as those shown in Figure 1. Table 3 below includes the cruise dates and number of water samples taken for oxygen concentration (O_2) and salinity (S).

New equipment acquired this FY included the fabrication of a small CTD frame.

FY 2004		FY 2003	
Date	Water Samples	Date	Water Samples
Jan 8-9, 2003	55 O2, 46 S	Nov 20, 2002	43 O2, 44 S
May 6-7, 2004	47 O2, 43 S	Mar 22, 2003	59 O2, 49 S
July 4-5, 2004	56 O2, 46 S	July 16, 2003	56 O2, 46 S
Aug 27-28, 2004	55 O2, 42 S	Oct 2-3, 2003	57 O2, 43 S
100% of Planned Cruises		100% of Planned Cruises	

Table 3: Cruise dates for 2-day calibration cruises on the RV Walton Smith.

Task 2: Deep Western Boundary Current time series
A full water column cruise of CTD, Lowered ADCP on the NOAA Ship RONALD H. BROWN (one per year scheduled) was conducted within the Florida Straits and east of Abaco Island, Bahamas. At each station, a package consisting of a Seabird Electronics Model 9/11+ CTD O_2 system, RDI Lowered Acoustic Doppler Current Profilers, and 24 ten-liter Niskin bottles, was lowered to the bottom. This provided profiles of velocity, pressure, salinity (conductivity), temperature, and dissolved oxygen concentration. Water samples were collected at various depths and analyzed for salinity and oxygen concentration to aid with CTD calibration.

The hydrographic cruise this year took place on the NOAA Ship RONALD H. BROWN from September 21 to October 3, 2004. A total of 41 stations were occupied at the locations shown in Figure 2. Table 4 lists the cruise dates and bottle samples taken compared to previous years. Five inverted echo sounders (IES) were deployed as shown in Figure 2 including: one IES, three IES with pressure sensors (PIES) and one IES with pressure sensor and bottom current meter (C-PIES). A new shipping container (10 feet by 10 feet by 8 feet) was acquired to aid in equipment storage and delivery to the ship.

FY	Date	Stations	Bottle Samples	Comments
2004	Sep, 2004	42	634 O2, 629 S	5 IES mooring deployments
2003	Feb, 2003	54	844 O2, 843 S	3 IES Mooring recoveries, Short Seabeam in Florida Straits
2002	June 2002	57	924 O2, 924 S	Extended Seabeam survey east of Abaco Island, SF6 samples.
2001	2001	33	607 O2, 659 S	4 IES mooring deployments

Table 4: Cruise dates and water samples taken for Large Vessel full water column surveys of the Deep Western Boundary Current.

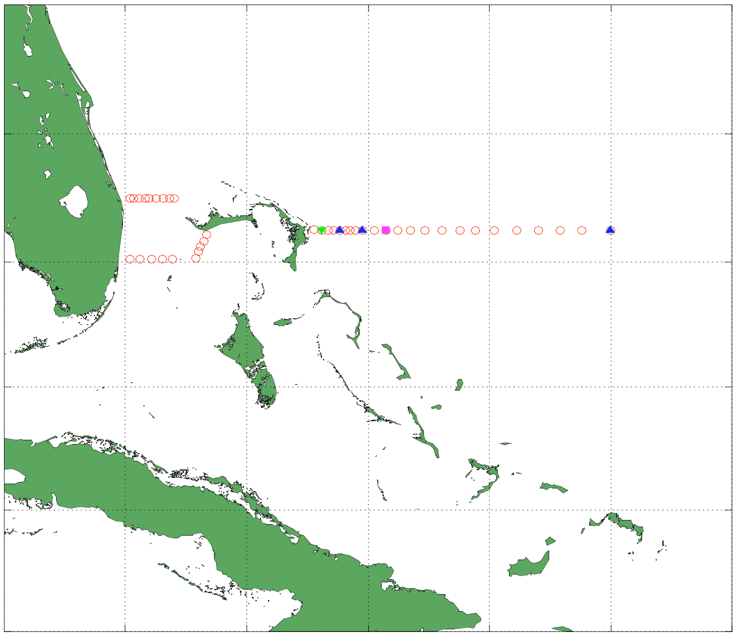


Figure 2: Locations of full water column hydrographic stations sampled on the NOAA Ship Ronald H. Brown cruise in FY 2004. Red circles denote CTD sites. Blue and green triangles denote PIES and IES moorings respectively, while the pink square denotes a C-PIES mooring.

Where data are stored, data distribution, availability and access to data:
All data are stored at AOML and are available upon request. Cable data are collected and stored on a computer in the Bahamas and downloaded daily to AOML. Preliminary cable data are available via web interface upon request and will be more freely available once the new calibration system is operational. CTD data will be distributed to NODC and the WOCE hydrographic program office when final calibration is complete.

How data are currently being used and shared:
Small boat calibration data are processed to supply a total transport of the Florida Current and are used to check the cable voltage measurements. Water bottle sample data are used to calibrate CTD data, to compute property fluxes within the Deep Western Boundary Current and Florida Current. Water properties of the Deep Western Boundary Current are used to infer time scales of deep-water renewal and monitor the intensity of the thermohaline circulation. All data are stored at AOML and are freely available upon request.

Task 1, Continuous cable voltage recording: Unanticipated costs included substantial processing time to quality control the voltage data to produce transport numbers. See "*Budget Justification*" for further details. Recent equipment damage may result in additional unanticipated costs.
Task 1, Calibration cruises: Additional unanticipated and unfunded costs included the loss of the dropsonde equipment in 2003 that required a replacement, purchased by AOML. We have been borrowing the University of Miami's CTD package, frame, rosette and bottles because our large frame is too big for the RV Walton Smith. This year we began the process of building our own small CTD frame.
Task II, DWBC Time Series: No additional costs incurred.

Problems encountered:

Task 1, Continuous cable voltage recording: Problems include only the recent loss of electricity and phone service in the Bahamas after the passage of Hurricanes Frances and Jeanne. The equipment may have been damaged when the building lost its roof. An upcoming visit will ascertain the extent of the damage and determine what repairs are necessary.

Task 1, Calibration cruises: Problems included the failure of the new dropsonde to accurately record GPS positions in August. We suspect this was due to a new antenna design and the increasing sea-state due to the approach of Hurricane Frances.

Task II, DWBC Time Series: Hurricane Jeanne cut short several stations within the Florida Strait and along the eastern most end of the DWBC section. The NOAA Ship Ronald H. Brown delayed departure from Charleston for 34 hours due to engineering and staffing issues that resulted in fewer Sea Days than requested assigned to the project.

Logical considerations (e.g., ship time utilized):

- Clearances to do technical work in the Bahamas to the recording equipment are necessary and very difficult to obtain.
- Blanket clearances are necessary to work on calibration cruises due to the short lead-time for scheduling the cruises.
- Bahamian clearances for the large ship Deep Western Boundary Current cruises are also necessary.
- This work would not be possible without the considerable help of BattelCo, the Bahamian telephone company, for the use of their facilities to store our equipment, install phone lines and to instrument their telephone submerged cable.
- Ship days required:

Ship	Seadays per trip	Trips per year	Total Seadays (including weather days)
NOAA Ship Ronald H. Brown	14	1	16
RV Walton Smith	2	4	10
Charter Fishing Boat	1	8	10

Research highlights:

Task 1: Continuous transport of the Florida Current

Voltage estimates recorded from the submarine cable were corrected for geomagnetic variations due to the changing ionosphere and then adjusted using the transfer function that relates voltages to total flow through the Florida Straits (Larsen, 1992). Preliminary estimates of the flow are shown in Figure 3 and are available on the project web site. Several features of note appear to be related to the failure of the reference electrode at Eight Mile Rock, Grand Bahamas. Data gaps in the record will remain until personnel become available to recover the data.

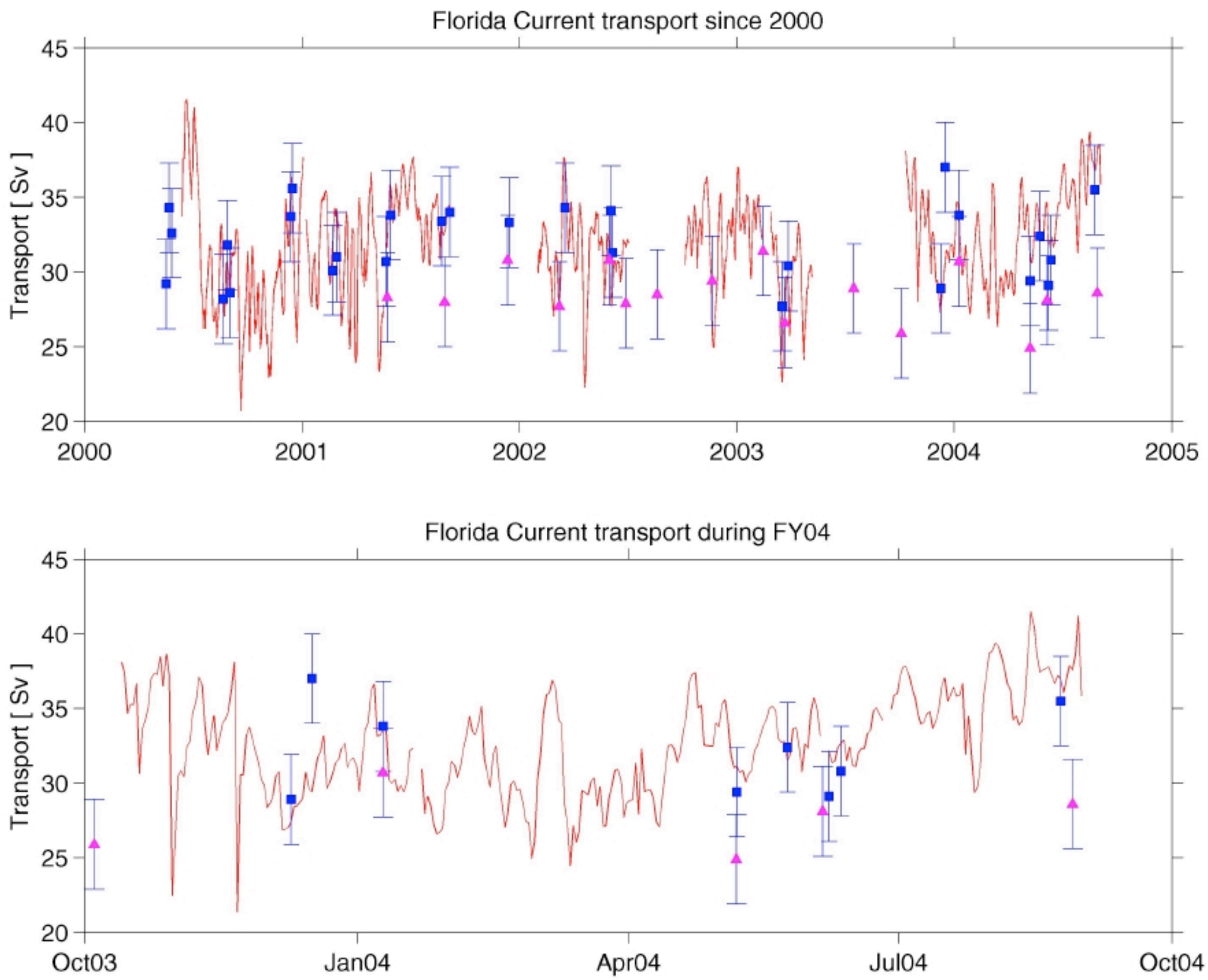
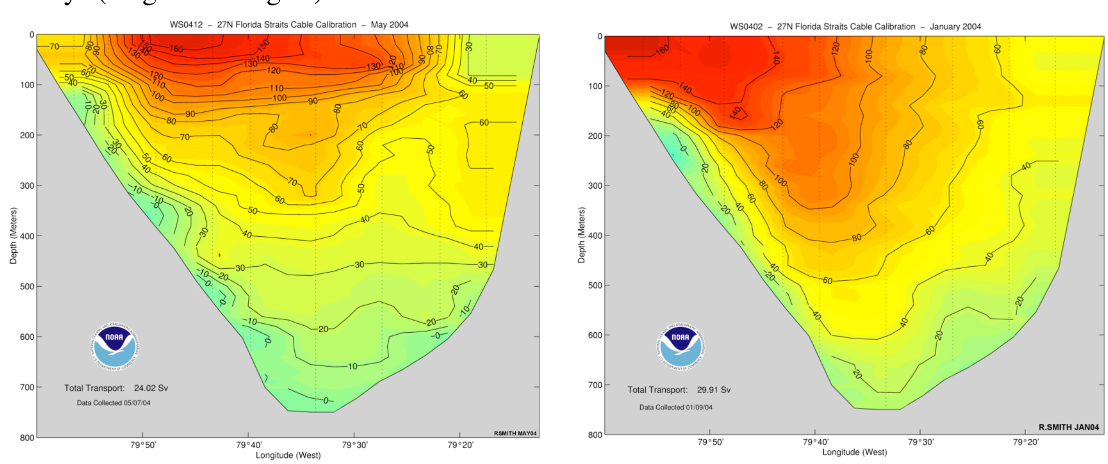


Figure 3: Daily estimates of Florida Current transport determined by voltages induced on a submarine telephone cable. Transports are given in Sv (1 Sv = 10^6 m^3 s^{-1}). Symbols with error bars represent calibration cruises from: small charter boats (blue squares) and full water column surveys (magenta triangles).



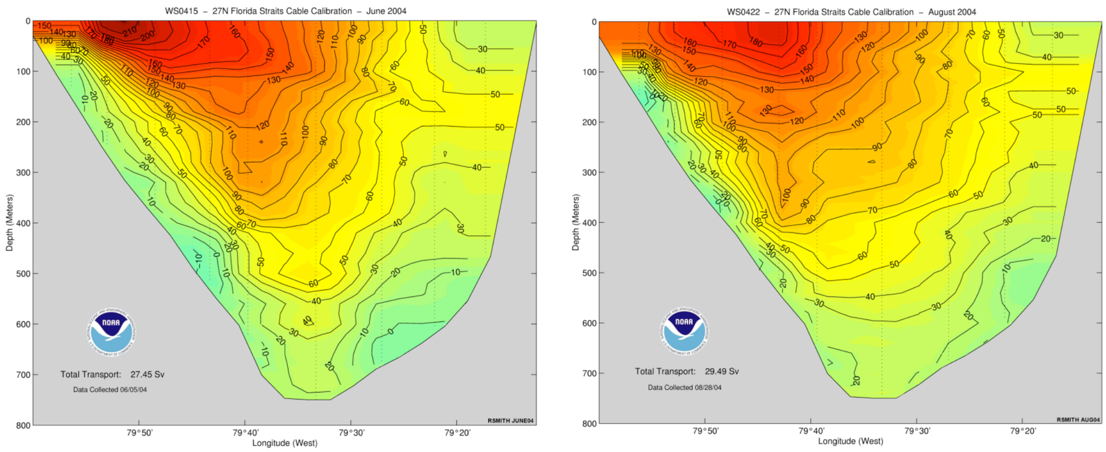


Figure 4: Full water column calibration cruises show the complex vertical structure of the Florida Current.

Task 1: Florida Current calibration cruises

Calibration cruises show transports of the Florida current varying from 26.9 to 30.8 Sv. Note that, the current is not always monotonically northward. A subsurface southward flow between 150 to 500 meters deep along the western side of the Strait can be seen in several of the full water column sections.

Task 2: Deep Western Boundary Current Time Series

Full water column Deep Western Boundary Current CTD/LADCP sections show the arrival of newly formed Labrador Sea water in the center of the subtropical gyre (T<3.7ºC, S < 34.98) beginning in late 1994 (Figure 5). Since its first arrival, the Labrador Sea Water is seen to become progressively colder and fresher and its influence is felt further and further offshore.

In preparation for the inverted echo sounder deployments in FY 2004, a preliminary test of the use of PIES for measuring the variability of the Deep Western Boundary Current and the Antilles Current utilizing three inverted echo sounder records (IES) and two bottom pressure records (BPR) from 1996-1997 was completed. Comparisons are shown between transports estimates derived from the IES and BPR (Figure 6) showing excellent agreement with the more expensive and traditional current meter moorings (Meinen *et al*. 2004).

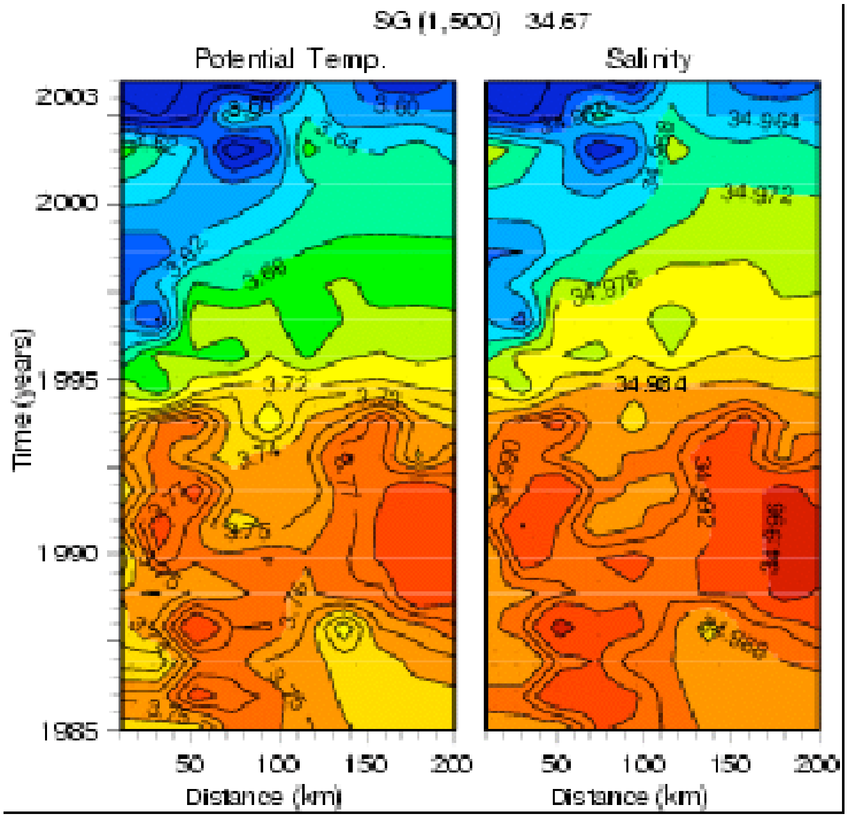


Figure 5: Potential temperature and salinity time series within the Deep Western Boundary Current off Abaco Island, Grand Bahama on the density surface representative of the Labrador Sea Water ($\square_{1.5}$ = 34.67, approximately 1700 meters). The time series shows the arrival of cold, fresh Labrador Sea Water in late 1994, which steadily extends offshore through the 2003 cruise.

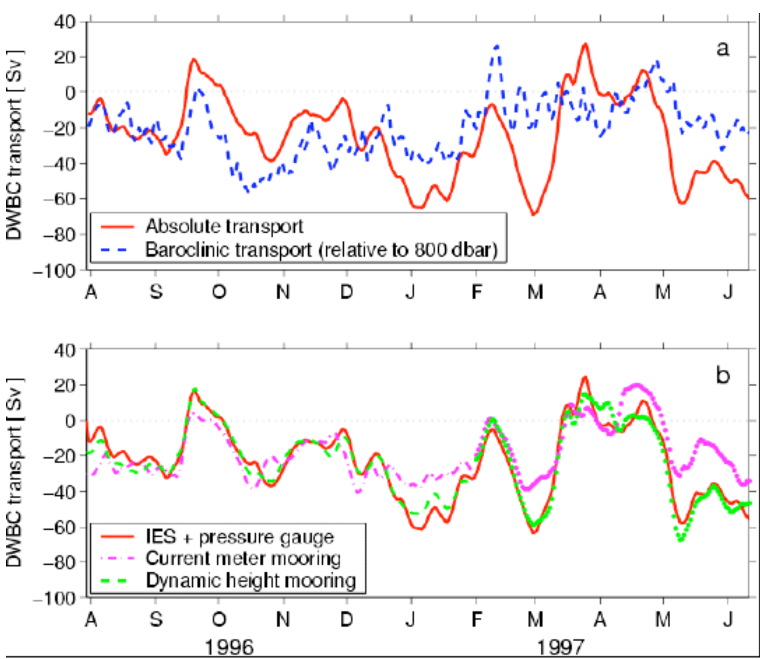


Figure 6: Transport of the Deep Western Boundary Current offshore of Abaco Island. a) Baroclinic transport, relative to an assumed level of no motion at 800 dbar, and absolute transport integrated between 800 dbar and 4800 dbar and between mooring sites B and D. b) Absolute transport from the IES combined with the bottom pressure measurements compared to absolute transport integrated from the observations of the coincident current meter line. Because the current meter data were only available at 1200 dbar and below, the transports in this panel are integrated only over 1200-4800 dbar. Also shown is the transport determined by calculation dynamic heights from the temperature sensors

moored alongside the current meters, utilizing the same bottom pressure sensors for the barotropic reference as were used with the IES data. Current meter and dynamic height mooring estimates are dotted after February 1997 because the mooring at site B lost its top portion at that time. Units are in Sverdrups (1 Sv = 10^6 m^3 s^{-1}).

3.3a. The Tropical Atmosphere Ocean (TAO) Array

by Landry J. Bernard, III and Daniel J. Laurent

PROJECT SUMMARY

This continuation proposal requests funds to maintain the Tropical Atmosphere Ocean (TAO) array as part of NOAA's effort to "Build a Sustained Ocean Observing System for Climate". TAO is the U.S. contribution to the TAO/TRITON array, a network of moored buoys spanning the tropical Pacific Ocean maintained in partnership with the Japan Marine Science and Technology Center (JAMSTEC). TAO/TRITON supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also underpins Climate Variability and Predictability (CLIVAR) research efforts on El Niño/Southern Oscillation (ENSO). Management of the array is consistent with the "Ten Climate Monitoring Principles". Program oversight at the international level is through the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A web site containing comprehensive information on both programs can be found at http://www.pmel.noaa.gov/tao/.

FY 2004 PROGRESS

TAO/TRITON Array

Background:

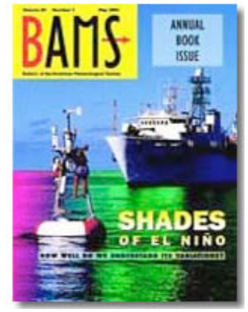
FY 2004 was the fourth full year of the combined TAO/TRITON array and the partnership with JAMSTEC is working well. NOAA maintains the portion of the array between 95°W and 165°E, while JAMSTEC maintains sites between 156°E to 138°W. JAMSTEC added three moorings along 130°E for its own purposes in FY 2002, though these moorings complement those of the TAO/TRITON array proper. Basic measurements from ATLAS and TRITON buoys are transmitted on the GTS and are merged into a unified data set available on the World Wide Web at PMEL (http://www.pmel.noaa.gov/tao/) and a mirror site in Japan (http://www.jamstec.go.jp/jamstec/TRITON).

TAO Project Highlights:

At present, TAO/TRITON data indicate the development of weak El Niño conditions in the tropical Pacific. Forecast models, many of which depend heavily on TAO/TRITON data for initialization, suggest that warming will continue into early 2005. As a consequence, weather patterns in the US and elsewhere around the world are likely to be affected as El Niño-related atmospheric teleconnections emanate from the tropical Pacific to affect the general circulation of the atmosphere. Pacific marine ecosystems and commercial fisheries may likewise be affected.

In December 2003, the TAO Project Office was awarded the 2003 Grace Hopper Government Technology Award ("Gracie Award") for "Leadership in the innovative application of information technology that contributes to the advancement of scientific knowledge and its application." The Grace Hopper Government Technology Leadership Awards are sponsored by Government Executive magazine and selected by a panel comprised of leading experts on the federal government's use of technology, drawn from government, prominent federal contractors and the academic community.

The TAO Project was highlighted on the cover of the May issue of the *Bulletin of the American Meteorological Society*. The cover story, authored by the Project Director, highlighted how far we have come, and how far we have yet to go, in our ability to understand and predict El Niño. The importance of sustained observations in the tropical Pacific was a central theme of the article.



Fieldwork:
PMEL is responsible for maintaining 55 ATLAS sites at and east of 165°E. At four of these sites (165°E, 170°W, 140°W, 110°W along the equator) current meters are attached to the ATLAS mooring lines and a nearby subsurface ADCP mooring is deployed. An ADCP mooring is maintained by JAMSTEC at 0°, 147°E. During the past year, the TAO Project deployed 63 ATLAS moorings and 4 subsurface ADCP current meter moorings in the tropical Pacific. The number of ATLAS deployments exceeds the number of ATLAS sites in the array because of mooring system failures or losses during the year, because some sites (like the equatorial current meter mooring sites at 110°W and 140°W) are turned around regularly on a 6-month rather than 12-month schedule and because cruise schedules are such that some moorings are deployed for slightly shorter than their 12-month design lifetime. There was also one ATLAS deployment for engineering development purposes included in these totals. For comparison, in FY 2003, 71 ATLAS (including 3 for EPIC) and 5 subsurface current meter moorings were deployed in the TAO array.

Ship Time and Sea Time:
In FY 2004, 264 days at sea were required to support the TAO portion of the TAO/TRITON array (221 days on the Ka'imimoana and 43 on the Ron Brown) a total of 688 PMEL person days at sea (number of people times days at sea) in support of TAO field work were required during FY 2003. For comparison, 267 days at sea (232 days on the Ka'imimoana and 35 on the Ron Brown) and a total of 658 PMEL person days at sea in support of TAO fieldwork were required during FY 2003. The increase in person days in FY 2004 was due mainly to PMEL sending the TAO Field Operations Manager to interact with NDBC personnel performing DART work from a TAO cruise.

Real-time Data Return:
Percentage real time data return for primary TAO variables integrated over all 55 sites for FY 2004 was as follows:

	AIRT	SST	T(Z)	WIND	RH	ALL
FY 2004	88	88	89	76	89	88
FY 2003	90	88	85	75	88	85

Real time data return for the entire TAO/TRITON array (including JAMSTEC TRITON moorings) was 86% for primary variables. Data return from the most recently recovered PMEL ADCPs in FY 2004 was effectively 100% at the four equatorial sites. For comparison, ATLAS data return from FY 2003 is shown in the above table. The returns for surface sensors are comparable, with relatively insignificant changes of ≤2%. Subsurface temperature data returns improved significantly (4%) in FY 2004, due to improvements in inductive telemetry hardware.

Subsurface temperature data comprise more than 70% of primary data, thus the increase in their data return resulted in a significant (3%) increase in overall data return.

After mooring recovery, data recorded on board the buoy are available and may augment data not available in real time. For this reason, combined delayed mode and real time data return for primary TAO sensors in FY 2003 was 92%, representing an increase over real time alone of 7%. Not all internally recorded data have been recovered yet for FY 2004. However, a partial accounting indicates an increase to the database of about 3% so far, for an overall data return of 91%. This number may further increase once a full accounting is possible.

Wind data return is lower than that for other sensors due to two factors. First, the sensor's placement at the top of the mooring exposes it to increased vandalism potential. Secondly, the wind sensors have a higher failure rate compared to other instruments. The failure is mainly in the vane circuitry and has been isolated to a single component. Consultation with the manufacturer has suggested that the grounding the sensor may improve reliability. Redesign and testing of the ATLAS wind system to provide grounding was completed in FY 2003 and all new mooring deployments in FY 2004 will have ground wind sensors.

In addition to primary ATLAS variables, additional measurements were made as part of research efforts supported by other programs. These measurements include ocean velocities, rain rate, salinity, shortwave and longwave radiation, and barometric pressure. These data are distributed via TAO web pages. TRITON sites also measure rain rate, shortwave radiation, and ocean velocity (at 10 m).

Shipboard Measurements:
CTD casts, and underway ADCP and thermosalinograph measurements, are conducted from mooring servicing cruises on the Ka'imimoana and Ron Brown. These data are an integral part of the TAO Project, providing in situ calibration checks on mooring sensor performance. They also provide hydrographic and current field information that helps to put the moored time series measurements into a broad scale hydrodynamic context. The data are a valuable resource for climate model development and climate analyses, and are frequently used together with moored times series data in scientific publications.

A total of 400 CTD casts (338 on the Ka'imimoana and 62 on the Ron Brown) were made on TAO cruises in FY 2004, which was a small increase over FY 2003 (383, with 338 from the Ka'imimoana and 45 from the Ron Brown). The shipboard ADCP data are forwarded to, processed, archived, and distributed by Eric Firing and colleagues at the University of Hawaii. Underway sea surface salinity measurements are processed at PMEL, then forwarded regularly to the IRD laboratory in Noumea for distribution (by CD-ROM) with other sea surface salinity data (http://www.ird.nc/ECOP/siteecopuk/cadres.htm).

Problems with the shipboard ADCP data quality from the NOAA Ship Ka'imimoana identified by Eric Firing and colleagues in FY 2003 were addressed by the installation of a new 75 kHz RDI Ocean Surveyor ADCP and a POS/MV attitude sensor in FY 2004. Initial analysis of the data by the University of Hawaii indicates that the new system is working well and data quality has improved.

Engineering Tests:
There was one ATLAS deployment for engineering development purposes at 5°N, 140°W in September 2003. This mooring was deployed to test two types of sonic anemometers for possible replacement of the RM Young propeller and vane assembly, namely the Handar WS425

Ultrasonic and the Gill model Windsonic. The system also included a KVH C100 compass, as a possible replacement for an older model KVH which has been problematic on some ATLAS systems. The field test also includes a standard wind RM Young wind sensor for comparison. Preliminary results were encouraging and were reported at the OCO Annual System Review and the 2nd High-Resolution Marine Meteorology (HRMM) Workshop, both in April 2004 in Silver Spring, MD. The mooring was recovered in May 2004 and analysis of high temporal resolution data from the system is planned. Sonic anemometers and new compasses require significantly more power than the present ATLAS system. Inclusion of these sensors into a 3rd generation ATLAS system may include increased battery packs, conversion from alkaline to lithium batteries, and/or reduction in sampling frequency or duration.

Another engineering effort to improve wind data return was to ground the existing R.M. Young anemometers. This required new connectors, modification of the ATLAS system mast, internal wiring and top section cable. Several modified systems were deployed in FY 2004 including reinstrumentation of the test mooring at 5ºN, 140ºW and deployment of a second test mooring at 2ºN, 140ºW. Wind data from the test systems were comparable to that from the non-grounded systems, and no vane circuitry failures (as noted in 2.5 above) occurred. Based on these results, the decision to ground all systems deployed in FY 2005 was made.

The Project participated with the University of Washington and Aeromet, Inc., to compare several precipitation gauges on Kwajalein Atoll. The experiment, which began in July 2003 and continued through December 2003, compared the sensor used on TAO and PIRATA moorings (R.M. Young model 50203-34, modified for use with the ATLAS system) with other gauges (Tipping bucket, Hasse, Disdrometer). Results of the intercomparison were presented at the Eighth International Conference on Precipitation in Vancouver B.C. in August 2004, by Dr. Sandra Yuter of the University of Washington. The conclusions included the fact that all sensors yielded similar results when daily accumulations were greater than or equal to 10mm.

PMEL is also testing a modified TAO rain gauge designed to decrease spiking found in the present version gauge. Preliminary results indicate that the modifications have improved the sensor performance. Testing and analysis of modified systems will continue in FY 2005.

We investigated the feasibility of measuring a high vertical resolution current profile in the upper 50m from an ATLAS mooring. Initial results indicate that the presence of fish around a surface mooring will significantly bias the data. While disappointing, this result will factor significantly into plans for other research investigations such as PUMP. Use of high vertical resolution current profilers from other mooring systems may still be considered.

Guest Investigator Research Projects Using TAO Moorings and TAO Cruises:
One of the primary missions of the TAO/TRITON array is to provide real-time data for improved detection, understanding, and prediction of El Niño and La Niña. The primary function of the NOAA Ship Ka'imimoana is to service buoys of the TAO/TRITON array. However, the TAO Project Office actively promotes use of the Ka'imimoana and, when it is used for TAO cruises, the Ron Brown for other meritorious scientific investigations that are of relevance to NOAA's mission. These projects are developed, funded, and lead by investigators from NOAA laboratories, other national research laboratories, and academia. Two categories of ancillary projects are described which are (a) ongoing and (b) one-time. An ongoing project is either planned or has been onboard already for more than one year. A list of PIs, their institutions and project titles are itemized below. The name of the ship from which the work is done (KA or BROWN) is indicated in parentheses.

a. Ongoing ancillary projects on TAO cruises for FY 2004:
<u>Project, Principal Investigator, Institution (Ship)</u>
Underway CO_2, Richard Feely, NOAA/PMEL (KA and BROWN)
Turbulent flux measurements and wind profiler, Chris Fairall and Jeff Hare, NOAA/ETL (BROWN)
Atmospheric monitoring, balloon radiosonde profiles, Nick Bond, NOAA/PMEL (BROWN)
Barnacle Project, Cynthia Venn, Bloomsburg University (KA and BROWN)
Carbon cycle, Michael Bender, Princeton University (BROWN)
Dissolved Inorganic Carbon (DIC) Analysis, Andrew Dickson, Scripps Institution of Oceanography (KA)
Argo float deployments, Greg Johnson, PMEL (KA)
Global Drifter Program, Robert Molinari, NOAA/AOML (KA and BROWN)
Iron limitation, Mike Behrenfeld, NASA/Goddard (BROWN)
CO_2 moorings, Chris Sabine, NOAA/PMEL (KA)
Bio-optical measurement and nutrient analysis, Francisco Chavez, MBARI (KA)
Haruphone mooring recoveries/deployments, Robert Dziak, NOAA/PMEL (BROWN)
Tsunami/DART mooring recovery deployment at 8.5°S, 140°W, NOAA/NDBC (KA)
Bigeye mooring deployments, Rusty Brainard, NOAA/NMFS (KA)
Acoustic rain gauges on ATLAS moorings, Jeff Nystuen, University of Washington (KA and BROWN)
Atmospheric radiation, Mike Reynolds, Brookhaven National Laboratory (BROWN)
Underway ADCP, Eric Firing, University of Hawaii (KA and BROWN)
Underway pO_2/pN_2- Gas Tension device and O_2 probe, Craig McNeil, Univ. of Rhode Island (BROWN)
Underway CIRIMS skin temperature device, Andy Jessup, UW/APL (BROWN)
O_2, N_2, Ar, CO_2 underway sampling, Jan Kaiser, Princeton University, (KA)
Underway DMS sampling, Tim Bates, PMEL, (BROWN)
Nitrate and O_2 isotope analysis, Patrick Rafter, Scripps Institution of Oceanography (KA)

b. One-time ancillary projects on TAO cruises for FY 2004:
Underway DMS sampling, Barry Huebert, University of Hawaii, (BROWN)
Membrane Inlet Mass Spectometry, Blake Sturtevant, Princeton University, (KA)
Spondylus buoy recovery, Jorge Cardenas, INOCAR, (KA)

TAO Project Web Pages:
The TAO Project continues to update the content and functionality of its web site (http://www.pmel.noaa.gov/tao/). This site provides easy access to TAO/TRITON and PIRATA data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. For FY 2004, TAO web pages received a total of 21,016,647 hits, about the same as in FY 2003 (22,136,074). Also during FY 2004, a total of 11,591 separate user requests delivered 153,502 TAO data files. These numbers are up 16% and 44%, respectively from the year before.

We had hoped to begin inclusion of TRITON salinities, radiation, rainfall, and currents to the TAO/TRITON web pages in FY 2004, but the development of a new TRITON Data Management System at JAMSTEC, which is necessary for the TAO/TRITON web page enhancement, is behind schedule.

Operational Use of TAO/TRITON:
TAO/TRITON data are distributed to operational centers such as NCEP via the GTS. These data are used routinely in climate forecasting and analyses. The data are also used for weather and

severe tropical Pacific storm forecasting. A weekly ftp transfer is routinely made to the NCEP coupled modeling project so as to ensure maximum ocean data availability for coupled model ENSO forecasts. TAO data placed on the GTS include spot hourly values of wind speed and direction, air temperature, relative humidity, barometric pressure, and sea surface temperature. Daily averaged subsurface temperature data are also transmitted on the GTS. The TAO Project Office has been working with Service Argos to include ATLAS salinity data on the GTS. Progress has been made towards this end, with modifications to the GTS subsystem completed and presently being tested.

Vandalism:
Vandalism continues to plague portions of the TAO/TRITON arrays. Data and equipment return are generally lower in regions of high tuna catch in the eastern and western equatorial Pacific. In addition to partial mooring hardware and instrumentation losses, 4 complete moorings systems were confirmed lost in the Pacific due to the effects of vandalism and another 2 moorings are suspected to be lost, but not yet confirmed. For comparison, 7 mooring systems were lost in FY 2003.

Efforts to combat vandalism continue, though it is not clear they are making much impact. These efforts include distribution of information brochures to national fishing agencies, fishing boats in ports of call, and industry representatives, and have contributed to international efforts to decrease vandalism through the DBCP. We may replace the attractive RM Young wind sensor with a less conspicuous sonic anemometer if tests of the latter prove encouraging and funding for system upgrades become available.

FY 2004 TAO Transition Accomplishments:
The revised Transition Plan for the operation and maintenance for the Tropical Atmosphere Ocean (TAO) buoy array was provided to the Office of Global Programs March 2004. The TAO Transition is being conducted in accordance with the high level guidance provided in the NOAA Executive Council (NEC) approved plan. The revised plan, the result of tasking received in November 2003 from the Climate Program Manager, details the management of the tasks, cost, and schedule for the TAO transition, establishes the foundation for sustained operation and technology refresh after the transition and describes further cooperation between PMEL and NDBC.

The TAO Transition Plan of March 2004 was briefed to the NOAA Observing System Council (NOSC) in March 2004, at the NOAA Climate Observation Program Annual System Review on April 14, 2004, and to the Climate Observing System Council (COSC) in April 2004.

Based on comments received from the NOSC and COSC reviews and the PA&E review of the TAO Transition Plan of March 2004, the plan was rewritten and submitted to the Office of Global Programs on August 31, 2004. This revised plan was briefed to the NOAA Deputy Administrator on September 15, 2004. The TAO Transition Plan of August 31, 2004, is now being executed.

3.4a. ENSO Observing System, XBT component, Task 1-Operations

by Steven K. Cook and Robert L. Molinari

PROJECT SUMMARY

General overview of the project, including brief scientific rationale:

The primary objective of the AOML XBT component of the ENSO Observing System is to provide oceanographic data needed to initialize the operational seasonal-to-interannual (SI) climate forecasts prepared by NCEP. Specifically, AOML manages a global XBT network that provides subsurface temperature data. The subsurface data are used in the initialization of the SI forecast models and have been shown to be necessary requirements for successful predictions. Global coverage is now required as the forecast models now not only simulate Pacific conditions but global conditions to improve prediction skill. Secondary objectives of this project are to use the resulting data to increase our understanding of the dynamics of SI variability, to perform model validation studies and to quality control delayed mode data to climate research standards. Thus, this project addresses both operational and scientific goals of NOAA's program for building a sustained ocean observing system for climate.

Statement about how your project addresses NOAA's Program Plan for "Building a Sustained Ocean Observing System for Climate":

This project provides critical data for initializing SI forecasts. The data resulting from this project will also address objectives 3 and 4 (i.e., the heat content and air-sea flux elements) of the OCO Program Plan.

Statement about how your project is managed in cooperation with international implementation panels, in particular the JCOMM panels:

The Voluntary Observing Ship (VOS) XBT Program is a participating member of JCOMM and JCOMMOPS. The VOS XBT program is represented annually at the WMO/IOC Ship Observations Team (SOT) meeting and Steven Cook presently is Chair of the Ship of Opportunity Implementation Panel (SOOPIP), a JCOMMOPS subcommittee. Participation on these international panels provides an important mechanism for integrating and coordinating with other national or regional programs which, in the long run, improves our national climate mission by making more efficient and effective use of available resources.

Responsible institutions for all aspects of the project:

The VOS XBT program is a component of the GOOS Center located within the Physical Oceanography Division of AOML and manages NOAA's Voluntary Observing Ship (VOS) XBT Program. The VOS XBT Program utilizes the National Weather Service Global Telecommunications System (NWSGTS) gateway for the real-time distribution of data and the National Oceanographic Data Center (NODC) for the archival of delayed mode data.

Project web site URL and pertinent web sites for your project and associated projects:

http://seas.amverseas.noaa.gov/seas/goosplots.html

Associated projects:

http://www.jcommops.org

http://www,cmdl.noaa.gov,http

http://seas.amverseas.noaa.gov/seas

http://www://sahfos.org

http://www-hrx.ucsd.edu

http://www.aoml.noaa.gov/phod/benchmarks/index.html

Interagency and international partnerships:
The GOOS Center has close cooperative working arrangements across all NOAA Line Offices (NWS, NESDIS, NOS, NMFS and OMAO), the U.S. Navy and Coast Guard, several major national (SIO, WHOI, RSMAS, URI, UW and SCMI) and international (BSH, CSIRO, BOM, SABOM, JAMSTEC, IFREMER, IRD-Brest and IRD-Noumea) oceanographic and meteorological institutions as well as private contractors. The program also provides XBT's to international partners for deployment on lines of mutual interest. The partners provide all the ship greeting and data transmission functions, which reduces considerably the logistical load on the GOOS Center and in many instances provides data in regions that otherwise would not be accessible to us.

Statement that your project is managed in accordance with the Ten Climate Monitoring Principles:
This program is managed in accordance with the Ten Climate Monitoring Principles.

FY 2004 PROGRESS
Instrument/platform acquisitions for the fiscal year and where equipment was deployed:
Funding at $260.8 K and a price of $32.00 per probe purchases 8150 probes. XBT's are deployed along selected transects in the Pacific, Atlantic and Indian Oceans. In addition, 6140 probes were supplied to international partners primarily for deployment in the western tropical Pacific and tropical Atlantic Oceans.

Number of AOML deployments by calendar year – compare to the previous year:
2003 – 11,907
2004 – estimate, 14,000

Percentage of data return for fiscal year:
The ratio of XBT's deployed to real time data transmitted is essentially 100% except for profiles from High Density transects. Not every High Density XBT collected is transmitted in real time primarily due to time limitations while sampling, but all delayed mode data not transmitted in real time are still inserted onto the GTS within 30 days of the completion of each cruise. Probe failure remains consistently between 2% and 5% with expected higher failure rates in the higher latitudes during the hemispheric winters.

Measurements taken, where data are stored, data distribution, availability and access:
XBT data provide subsurface temperature data to a depth of approximately 800 meters along 30 selected transects in all three-ocean basins. Data are stored on the computer system on the ships on which we have installed Shipboard Environmental data Acquisition (SEAS) Systems. The real-time data are transmitted via Inmarsat Std. C. Automatic quality control tests are applied to the data and those profiles that pass are distributed on the GTS. An operator reviews those profiles that fail the automatic quality control procedures. The operator decides whether or not to send the data to the GTS. Full resolution data are stored on disks and obtained by ship greeters when the VOS return to port. The data are forwarded to AOML, placed in established formats and then sent to the National Oceanographic Data Center (NODC). Additionally, all Atlantic XBT data are scientifically quality controlled at AOML as NOAA's contribution to the GTSPP. These data are stored at the Atlantic Data Assembly Center located at AOML and returned to NODC after review.

How data are currently being used and shared:
XBT data are used in real time for ENSO monitoring and prediction and the initialization of climate models at centers for environmental prediction and in delayed mode for research concerning seasonal to decadal climate studies of the upper ocean thermal layer. There are no restrictions on sharing this information as it is distributed in real time on the GTS.

Where the data are archived:
All XBT data are archived at the NODC and a subset of all Atlantic XBT data are archived at the DAC located at AOML.

Problems encountered:
Volatile shipping industry requires considerable time and travel resources to continually recruit and re-outfit vessels for participation in the VOS. This volatility is particularly troublesome in the Indian Ocean, where we have not been able to maintain a portion of the low-density network. Late funding has precipitated an increase of air shipping vs. ground shipping to deliver on time XBTs to those participating Research and Voluntary Observing Ships that had pre-set and therefore inflexible time schedules.

Research highlights:
Research using XBT data during the last fiscal year was primarily directed at decadal signals in the northwestern subtropical Atlantic. Molinari (2004), in press, generated a fifty-year times series of Gulf Stream transport and position from an XBT line between N.Y. and Puerto Rico. Decadal signals of these properties were in phase with the North Atlantic Oscillation and a recirculation gyre observed south of the Gulf Stream. The XBT data also indicate that the extension and retraction of the Gulf Stream are in phase with SST signals that propagate along the Gulf Stream. Analysis in the paper demonstrates that Argo float data can capture upper ocean temperature features previously observed in XBT representations of these features. Continued interactions with international scientists have demonstrated the importance of continued XBT sampling in the tropical Atlantic. Specifically, AOML scientists are involved in planning of the African Monsoon Multidisciplinary Analysis project. The objectives of AMMA are to study the West African monsoon and its associated offshore features (i.e., the atmospheric waves that can generate tropical storms and hurricanes).

3.5a. CORC: Surface Fluxes and Analysis

by Dan Cayan

PROJECT SUMMARY

Dan Cayan's CORC effort is 1) to produce sea-air heat, moisture, and momentum fluxes, estimated from marine weather reports using bulk formulae, and 2) assess the usefulness of those flux estimates in representing variability on seasonal to multi-year time scales.

The primary source of long (several decade) records of air-sea fluxes is from human-observer ship weather reports via bulk formulae. Traditionally, monthly turbulent and radiative flux components have been estimated using aggregates of bulk formulae calculations over all observations collected each month. To assess diurnal variability and to avoid errors from visual sky cover, wind observations taken after dark, we are recalculating the short wave flux and the other flux components using only daytime observations. This daytime-based flux dataset begins in 1950 and is updated through 2002. Because other investigators will prefer to apply their own menu of bulk formulae, we are saving the individual weather variables required to calculate each flux component.

Observations of the heat, moisture and momentum fluxes are needed to understand and predict how the atmosphere drives the ocean, and how the variability that is contained in the ocean may influence the atmosphere. Because this variability operates on a range of time scales from synoptic periods to decades, it is important for the Ocean Observing System to include an envelope of observations from marine weather reports in order to understand longer period variability using diagnostic analyses and model experiments.

This Project is managed locally by Dan Cayan at SIO. This effort is broadly guided by monitoring principles 4 (evaluation of quality and homogeneity) and 10 (a data management system--in order to process and distribute these datasets).

Data are distributed from an FTP server ftp://tenaya.ucsd.edu/pub.

FY 2004 PROGRESS

We have produced a preliminary version of bulk formulae surface heat flux (short wave, long wave, latent and sensible components) estimates using only daytime, and only nighttime (for long wave, latent and sensible components) observations. These daytime and nighttime flux dataset covers 1950 through 2002. Because other investigators will prefer to apply their own menu of bulk formulae, we are saving the individual weather variables required to calculate each flux component.

As an area of interest to CORC, we have processed the individual marine reports from the COADS set over the eastern North Pacific region (165W-105W, 15N-35N) during the 1950-2002 period. This region contains about 240,000 daytime reports for each month during the 53-year period. There are more observations during daytime than nighttime, ranging from about 30,000 more observations during winter months and 80,000 more observations during summer months.

There are substantial differences between daytime and nighttime properties. Not surprisingly, northeast Pacific average air temperature (T_{air}) and sea surface temperature (SST) are warmer in daytime than nighttime. However, somewhat surprisingly, the amplitude of the day-night difference in SST is not much smaller than for T_{air}. A common measure of stability at the air/sea interface, ($SST-T_{air}$), is used in bulk formulae to regulate turbulent fluxes of heat, momentum and moisture. Interestingly, nighttime ($SST-T_{air}$) in the NE Pacific varies relatively little between winter and summer, with average values ranging between about 1.5 in late winter to 1.0 in summer. $SST-T_{air}$ is less in daytime than in the nighttime for each month and over most of the ocean basin, as determined from a separate analysis of the global $SST-T_{air}$ distribution. Also, in contrast to the nighttime case, daytime ($SST-T_{air}$) has more seasonal variation, from 1.0 in winter to -0.06 in early summer.

There are other daytime vs. nighttime differences that could introduce possible biases in the fluxes if all observations are included in the monthly flux estimates. For example, daytime-only cloud cover is greater than is night-time only in most months, by about .4 oktas or about 5%, over most of the global ocean, including the stratocumulus-dominated northern oceans (Figure 1). It is suspected that this may result from observer bias—nighttime observers report less cloudiness because they can't see the sky well enough. The shortwave flux from daytime-only observations is lower than that calculated from nighttime-only. Differences of the shortwave flux calculated from daytime-only vs. that from nighttime-only observations are typically –10 to –40 Watt/m^2. Also, daytime wind speeds tend to be higher by about 0.4m/s or about 5% (Figure 2). This tends to introduce a commensurate increase in the loss of heat that would be calculated from daytime-only vs nighttime-only observations. Together, greater observed daytime cloud cover and higher daytime wind speeds tend to decrease the shortwave heating and increase the latent and sensible heat losses calculated by daytime-only observations—i.e., a tendency for lower net heat flux.

This suggests that the seasonal cycle of turbulent fluxes may be more strongly controlled by daytime than nighttime processes. Implications for the surface fluxes of using the daytime subset appear to be: lower net (into ocean) shortwave fluxes, greater latent and especially sensible flux heat losses from the ocean. Work is underway to compute bulk formulae fluxes from the daytime and nighttime data, and to compute anomalies and evaluate the variability within this dataset.

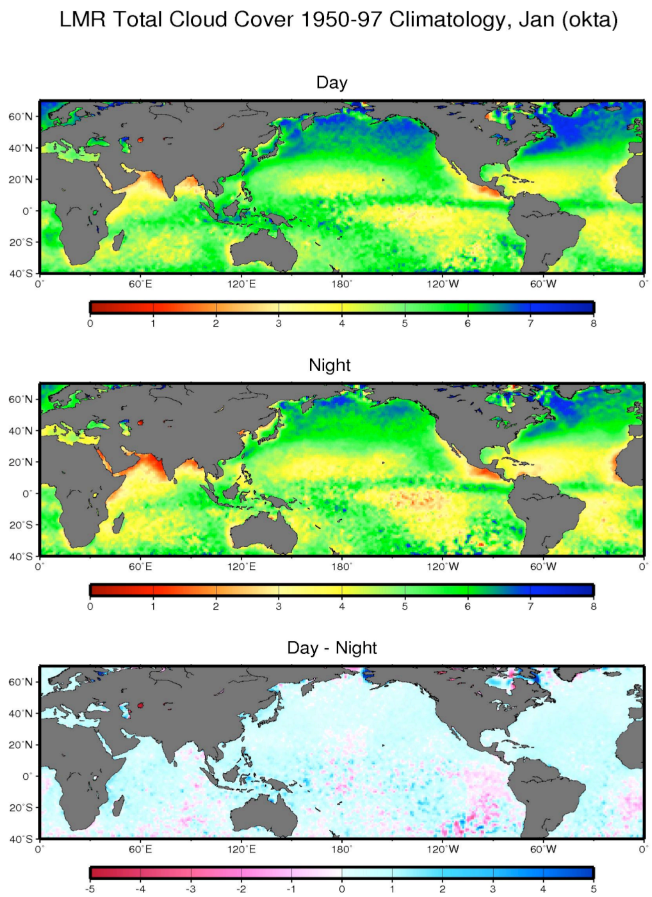


Figure 1. Cloud cover (oktas) from coads individual weather reports aggregated into monthly mean (1950-1997) for January. Daytime (top), nighttime (bottom) and daytime-nighttime difference (bottom).

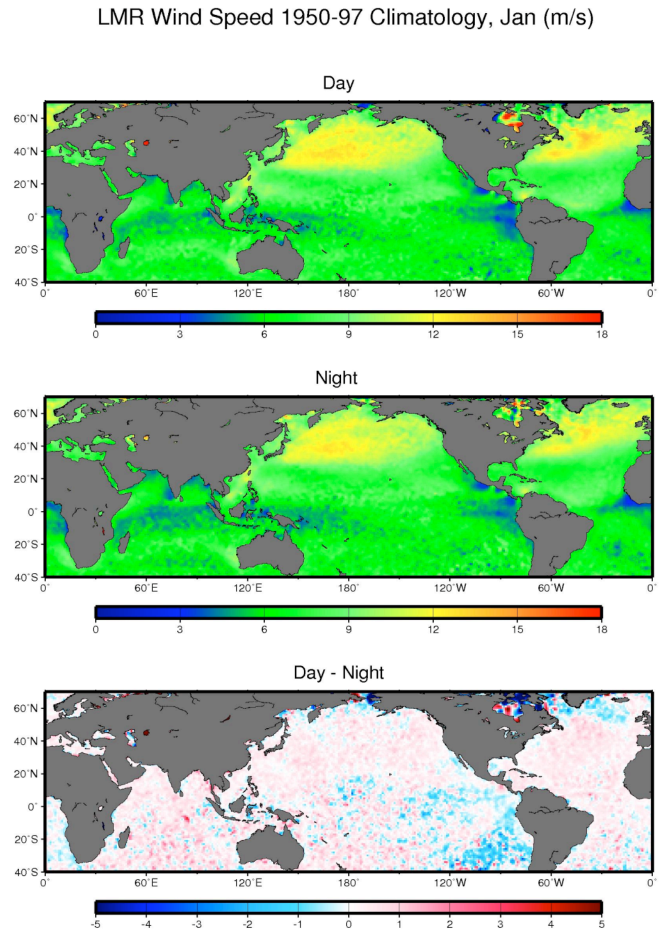


Figure 2. Wind speed (m/s) from COADS individual weather reports aggregated into monthly mean (1950-1997) for January. Daytime (top), nighttime (bottom) and daytime-nighttime difference (bottom).

3.6a. CORC: Four-Dimensional Variational (4DVAR) Data Assimilation in the Tropical Pacific

by Bruce Cornuelle, Detlef Stammer and Art Miller

PROJECT SUMMARY

The observational dataset of the tropical Pacific Ocean is both sparse and inhomogeneous, and one of the major challenges of data management is to combine the various data types into a coherent and useful picture of the ocean state, both physical and biological. The goal of this effort is to use the MIT general circulation model (MITgcm) and its adjoint (the ECCO assimilation system) to dynamically merge the Consortium for the Ocean's Role in Climate (CORC) observations, along with most other observations of the tropical Pacific: TAO, satellite sea surface height (SSH) and sea surface temperature (SST), surface drifters, and XBT, CTD and ARGO profiles. This will allow us to assess the capabilities of the MITgcm and its adjoint, determine optimal resolution, and explore the physical balances of the tropical Pacific. We also aim at producing optimized forcing fields, which are consistent with the model momentum, mass, salt, and heat budgets. Such a dynamically consistent framework will provide a unique tool to understand the variability of the tropical Pacific in greater detail than has been possible before. The optimized model states and forcing fields can be indeed used to explore mid-latitude influences on the tropics, examine ENSO variability through the years, and explore oceanic limitations on predictability of El Nino-Southern Oscillation (ENSO) events.

This project addresses section 6.12.3, subtask 3, of NOAA's Program Plan for building a sustained ocean observing system for climate: Four dimensional data assimilation including GODAE.

The project is managed as part of the Consortium for the Ocean's Role in Climate, serving the observational programs in CORC, which are reporting separately (e.g., High-Resolution XBT sections).

SIO is the primary responsible institution. Detlef Stammer is now at the University of Hamburg, and his involvement has declined. MIT is critical for the support of the MITgcm and the ECCO assimilation system, but is not supported as part of this project.

Project web site is http://ecco-group.org.

The project is managed in accordance with the Ten Climate Monitoring Principles, particularly principle 10.

FY 2004 PROGRESS

The data acquisition efforts are being reported separately, we focus here on progress in the data assimilation. Over the course of the earlier years of the project, a $1/3^{\circ}\times1/3^{\circ}$ model of the tropical Pacific was configured and run using a variety of initial conditions and forcing sets, including forcing and initial conditions from the global $1^{\circ}\times1^{\circ}$ assimilation by the ECCO project, headed by Detlef Stammer. The inner model has been run first in forward mode, for validation with data and sensitivity studies in preparation for assimilation experiments. The comparisons to observations, which have been evaluated for several different 9-year integrations (01/1992-12/2000), show promising agreement between the model outputs and the observations (Figure 1-2), and we have concluded that the model is sufficiently capable to be used for data assimilation.

In the current year, forcing fields, initial and boundary conditions were adjusted to bring the model into more consistency with TOPEX sea surface height (SSH), Reynolds sea surface temperature (SST), and Levitus temperature (T) and salinity (S) profiles over 1-year durations, for 1998 and 1999. The assimilations have required several innovations to make them work, including novel methods for adjusting the open boundary conditions and for removing extreme sensitivity from the adjoint of the model (see Problems Encountered below). The assimilation system is now working routinely. Several runs were first performed to find the best initial guess for the control parameters, revealing that the mean of the ECCO forcing corrections provide the lowest cost function value. After 30 iterations, the assimilation has improved the overall model fit to the data by more than 55% (Fig. 3). This is significant since the assimilation starts from an already optimized initial guess. This was also true for all the individual observations cost terms, which show a continuous decrease in the Model/data misfit (Fig. 4). The adjustments to the NCEP forcing fields produced by the assimilation are reasonable (Fig. 5). Moreover, early results suggest that the forcing adjustments are not strongly sensitive to the starting guess.

Problems Encountered:
The transition of the assimilation system from the 1-degree ECCO global model to the 1/3 degree tropical Pacific was not straightforward and two major difficulties were encountered. The first difficulty was due to the instabilities and nonlinearities of the higher resolution tropical Pacific model, which significantly limit the length of the model predictability, and therefore greatly increase the difficulty of the assimilation over long periods. This is a common problem with 4DVAR methods when applied to strongly nonlinear models and is related to the inability of the tangent linear model to provide good approximation to nonlinear perturbations. One major reason is that the linearized physical processes may not represent the major feedback loops between the nonlinear processes, leading to a projected exponential growth of initial perturbations with time without any saturation. Such unbounded sensitivities imply very small optimization steps, preventing any significant decrease in the total cost function. To damp the growth of sensitivities in our adjoint run, larger viscosity and diffusivity parameters were used in the model backward run. This enabled us to stabilize the adjoint model over the one-year assimilation period and therefore to successfully carry out the assimilation over this period.

The other major difficulty was related to the very strong sensitivity of the cost function, more precisely of the SSH term, to the velocities at the open boundaries. Indeed, a small variation in the barotropic component of the normal velocities at the open boundaries may produce a huge variation in the model SSH. To deal with these high sensitivities, a novel decomposition (based on the Quasi-Geostrophic model formulation) of the normal velocities at the open boundaries into barotropic and baroclinic components was introduced which allow us to specify different weights for each component in the optimization.

Biological model:
The latest MPI version of ROMS has been ported to the COMPAS cluster and the physical solution compares well with runs on other machines. ROMS is being used to develop the biological code that will be used with the MITGCM physical code. We currently have results from a simple, single tracer model simulating nitrogen-based nutrients with a uniform, light level mediated, loss term. We are currently improving this model by adding a phytoplankton component and have made runs for skill assessment. We have started to incorporate the single tracer biological code into the MITGCM code and plan to make comparison runs shortly. It is our current goal to continue enhancing the biological code on ROMS and port each enhancement to the MITGCM for comparison while moving on to the next enhancement on ROMS.

3.7a. CORC: Underwater Gliders for Monitoring Ocean Climate

by Russ E. Davis

PROJECT SUMMARY

Temperature, salinity and velocity are the fundamental variables for ocean climate observations. They are directly connected to the large-scale processes that shape climate variability and determine the storage and transports of heat and freshwater that defines climate change in the atmosphere and ocean.

The Argo array of profiling floats is now providing global coverage of subsurface temperature and salinity while a few of the TAO Array moorings provide sustained observations of velocity. Boundary currents are largely overlooked in today's observing system because of the difficulty of monitoring these narrow flows that often have significant transports. While Argo floats sample these currents, their density is much too low (typical spacing of 300 km) to resolve them, or even to determine their overall transports. It is not cost effective to significantly increase float density in these limited regions because floats remain in them only for short times; moorings are expensive and are impractical in strong and deep boundary currents like the Kuroshio or Gulf Stream.

The CORC underwater glider project aims to develop a cost-effective method to monitor temperature, salinity and velocity in specified regions where the small scales of the climate field demand a higher local density of observations than is feasible with floats. Gliders are buoyancy-driven vehicles, much like Argo floats, that use wings to glide forward while cycling up and down. The glider used for this effort is 'Spray' which was developed at SIO, initially under ONR funding. Our objectives are (1) to improve both sensor and platform performance in real-world circumstances, (2) evaluate the utility of the data gathered by these slow-moving platforms, and (3) begin monitoring regions where higher resolution observations are needed.

The objectives of the *Program Plan for Building a Sustained Ocean Observing System for Climate* to which gliders potential contribute are: document ocean carbon sources and sinks; document the ocean's storage and global transport of heat and fresh water; and document the air-sea exchange of heat and water and the ocean's overturning circulation. These are the same objectives to which Argo contributes. The plan identifies gliders as augmenting Argo with observations focused in selected regions, like boundary currents and deep-water formation sites, where higher observational density is needed. This project intends to first improve glider technology so that it can be effective in long-term observations and second to implement some sustained research observations so that readiness for operational monitoring can be evaluated.

At this developmental stage there are no national or international coordinating bodies for glider observations nor are gliders ready for inclusion in the Argo program. The project is managed at SIO and the investigator is an active participant in the Argo program, which glider development is meant to augment. SIO also has ONR and NSF projects that use gliders. The ONR project uses gliders to gather enough data in limited coastal regions to make possible synoptic-scale ocean predictions using data- assimilating models. The NSF project in collaboration with Breck Owens of WHOI is exploring glider observations of the Gulf Stream observations. The first transect from Massachusetts to Bermuda is under way as this is written. The CORC effort focuses on expanding the suite of glider sensors by implementing Acoustic Doppler current profiling, improving the long-term reliability and resistance to bio-fouling of sensors, and establishing regular sustained observations of the California Current on climate time and space scales to evaluate the utility of glider observations.

The sustained observations are being implemented in the Southern California Bight, which has been surveyed quarterly for over 50 years by the CalCOFI program. The glider observations cannot replace these ongoing surveys, which are based on collecting plankton, larvae and egg samples along with physical observations. The existence of a long and ongoing CalCOFI program will, however, simplify our commitment to the Ten Climate Monitoring Principles. Evaluation of the impact (hopefully synergistic) on CalCOFI will be key to establishing glider utility, documenting performance of unattended sensors and data homogeneity. Hopefully comparison of new and old systems will motivate eventual transition of this research system to operations. The data and metadata will be freely available through the Southern California Coastal Observing System web site soon to be established. Spray data from this program can now be examined at www.Spray.UCSD.edu.

FY 2004 PROGRESS

Early work in this program, which began in FY2001, showed that there were significant problems with Spray reliability. In one of our first sections off the California coast, a glider was lost after gliding about 250 km offshore. Figure 1 shows the track from this operation along with the measured ocean currents averaged from the surface to 500 m. Figure 2 shows the density section calculated from temperature and salinity reported through satellite in real time.

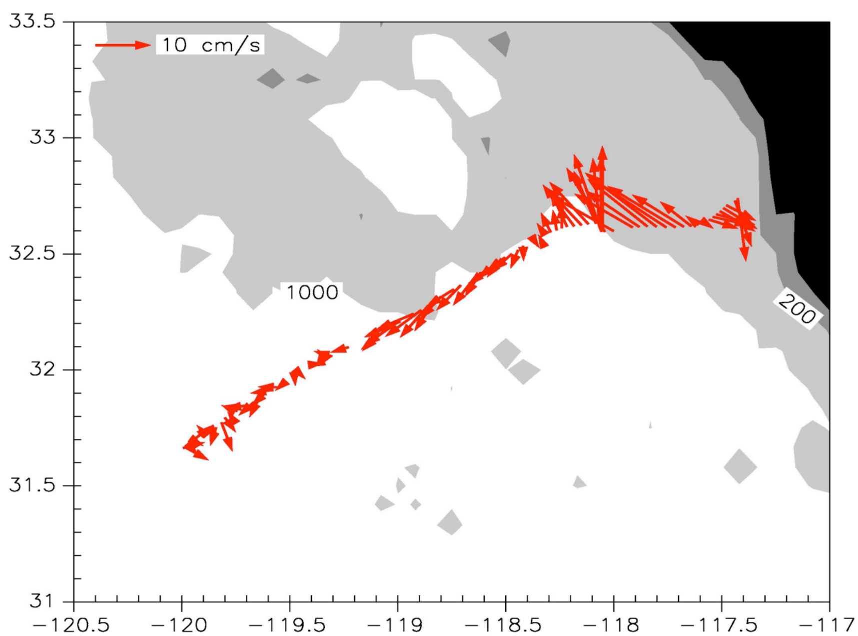


Figure 1. Trajectory of an early Spray glider section off San Diego. Vectors are average current between the surface and 500 dbar. The northwestward flow evident 50 km offshore may be a manifestation of the California Undercurrent or the Southern California Bight Eddy, a recurrent feature of the California Current.

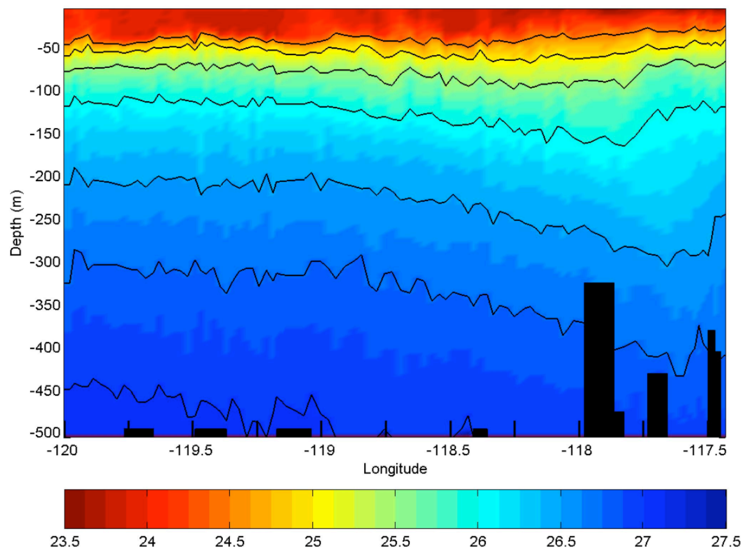


Figure 2. Potential-density section along the track depicted in Figure 1. The isopycnal slope between 118° and 119°W is consistent with the poleward flow seen directly. Such northwestward flow is common but not consistent element in the region. The inshore equatorward flow seen in velocity and density is not well known.

Failure of this early float precipitated a thorough design review of the systems most likely to have been involved: communication, buoyancy control, high-pressure integrity and the control mechanism for gliding. A number of modifications to these systems were designed and implemented in FY 2002. Following implementation of upgrades, a sequence of increasingly long local field tests was begun early in FY 2002. On the third test, the vehicle was lost because it was run over by a surface vessel, destroying its antennae but not sinking it. This initiated a second design review and the decision to switch to Iridium communication, to employ redundant communication/GPS antennas, and to install a backup Argos system

The ONR sponsored, August 2003, Autonomous Ocean Sampling Network II (AOSN-II) field experiment in Monterey Bay provided an attractive opportunity to prove out the various improvements introduced to Spray. Two NOAA-sponsored Sprays and three purchased with ONR funds were deployed along a 100 km stretch of coast spanning Monterey Bay. They were directed to run back and forth on offshore lines of approximately 80 km length. Figure 3 shows the trajectories and average velocities to 400 m from the five vehicles during a 10-day period early in the experiment. Gliders profiled temperature and salinity, generally to 400 m but occasionally to 750 m, and measured the vertically averaged water velocity as the difference between the measured motion through the water and distance made good. All five vehicles functioned perfectly for periods of 35-42 days before normal recoveries, showing a substantial duration advantage over Slocum gliders participating in the same exercise.

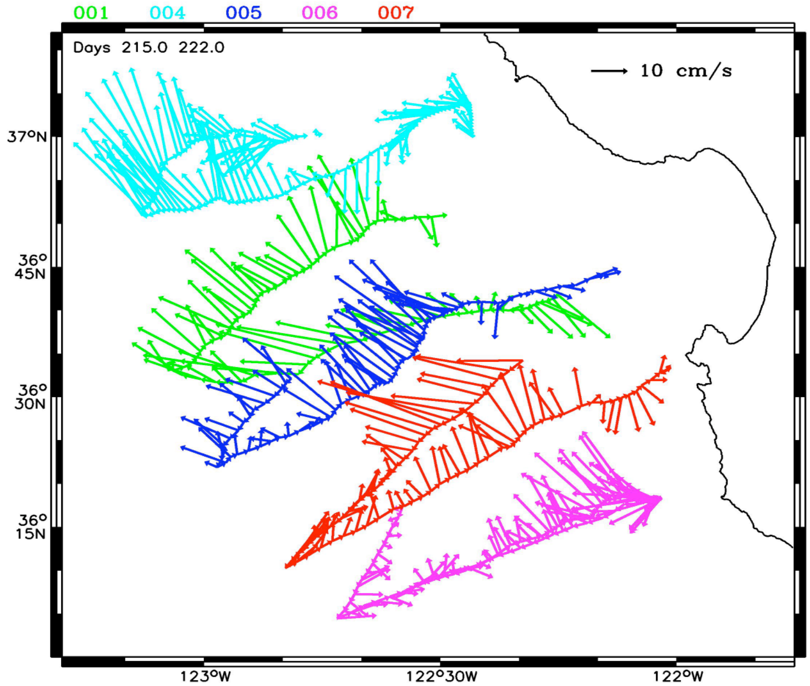


Figure 3. Velocity from five Spray gliders during 2-12 August 2003 while operating off Monterey Bay, CA. The solid line along arrow bases is the vehicle trajectory. Arrows represent average water velocity from the surface to 400 m. A strong California Undercurrent produces flow to the northwest at over 25 cm/s. Temperature and salinity profiles were measured on each dive-and-ascend cycle. Sampling extended over 42 days without interruption.

FY04 activity has focused on designing, implementing and testing new sensors and improved systems to rectify weaknesses exposed in the Monterey Bay operations:
(1) The PME conductivity sensor, which was unduly affected by bio-fouling in Monterey Bay, was replaced by a Sea Bird CTD similar to that used on most Argo floats. Unlike the Seaglider and Slocum gliders, we use the CTD's pump to optimize dynamic response, to improve corrections for dynamic response, and to provide a pumped water system that is protected from bio-fouling by poisons and can be used by optical sensors. (2) A Sontek 3-beam 500 kHz ADP was installed to directly measure vertical shear that can be combined with measured depth-average velocity to determine the full velocity profile. (3) A secondary hydraulic pump was introduced to avoid vapor lock of the primary buoyancy pump caused by air bubbles in the hydraulic system, a problem noted on one Monterey Bay dive.

In an NSF-sponsored collaboration with Breck Owens of WHOI, we have begun testing the ability of Spray to monitor climate signals in the Gulf Stream using periodic Spray transects from Cape Cod to Bermuda. Because the Stream is so much faster than the gliders, these will not be transects in the usual sense but rather should be regarded as sampling the changes across the strong western boundary current. Figures 4 shows the highly distorted path of Spray on the first crossing of the Gulf Stream along with the surface to 1000 m average current (this glider does not have an ADP). Because the glider forward velocity is much less than current velocities, the path was temporarily reversed to northward motion by a deep meander in the Stream. Figure 5 shows the temperature and salinity variations across the Gulf Stream – even though the path is highly distorted the glider is always headed across the current as deduced from SST maps and the velocity encountered. The critical question in this project is whether data collected in this manner are adequate to document climate-relevant changes in the Stream.

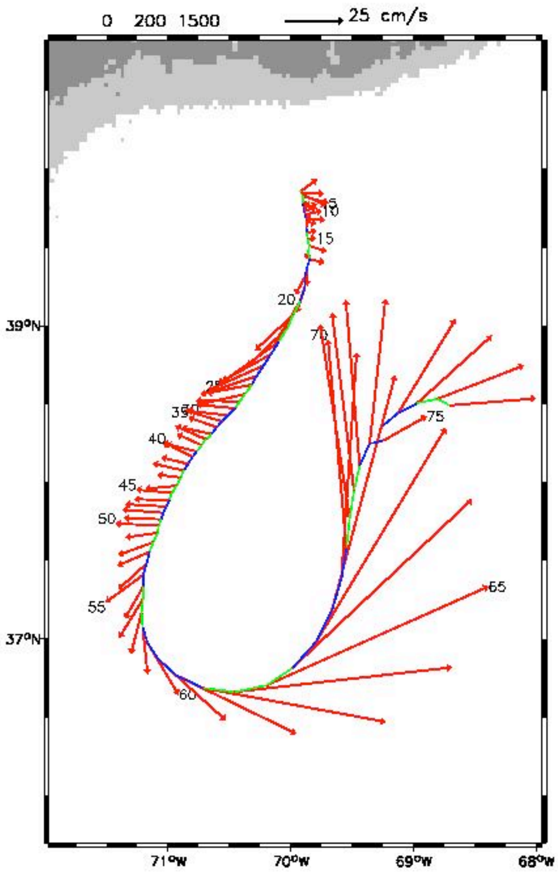


Figure 4. A Spray crossing the Gulf Stream. The blue-green line is the path of a Spray as it tries to cross the Gulf Stream and is caught in a deep meander. The red arrows (scale is at the top) are the depth-averaged current (from the surface to 1000 m) of the Gulf Stream. Shading at the top is bathymetry of Massachusetts with gray-scale breaks at 0, 200 and 1500 m depth. At all points along the path the glider is steered to be moving across the Gulf Stream.

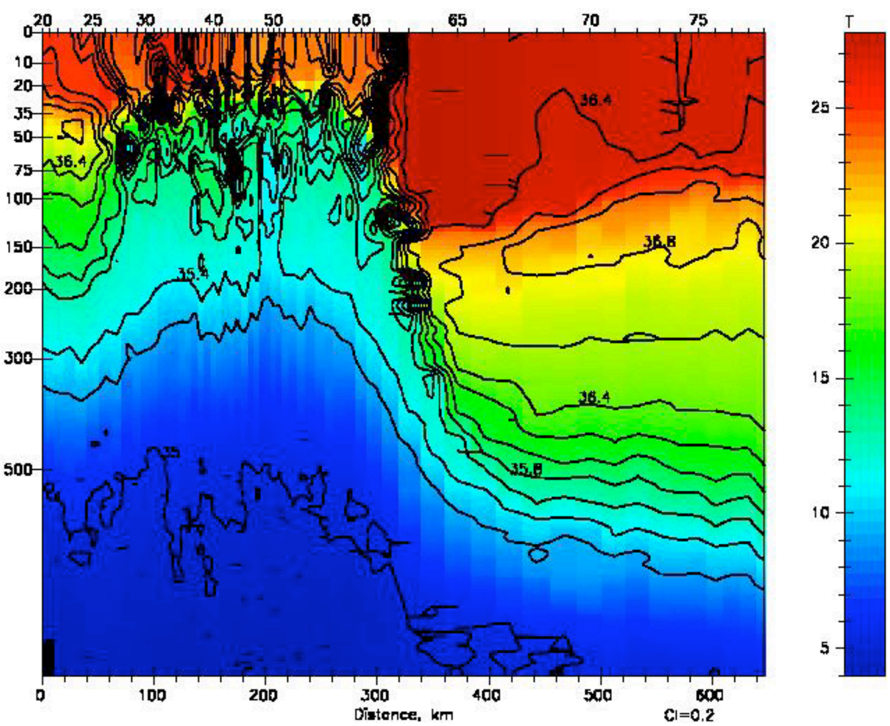


Figure 5. Sections of temperature (color shading) and salinity (line contours with interval of 0.2 psu) crossing the Gulf Stream. Depth scale is not linear. Horizontal scale is actual geographical movement in kilometers. "Stations" shown at the top are closely spaced when the glider is slowed by the current. The glider is steered across the instantaneous current at all times, regardless of the heading that is produced.

Performance Details. During FY04 we upgraded one previously constructed Spray with a Sea Bird SBE 41CP CTD and pumped water system and upgraded a second glider with a previously purchased Sontek 3-bean Acoustic Doppler current Profiler (ADP). We also began construction of 3 new gliders that will be put into service in FY05.

We tested the new ADP in two one-day field tests within 20 miles of SIO and tested the SBE CTD in three similar one-day tests. The data recovery from these missions was 100% but the records were short and the tracks chosen for logistic convenience, not scientific value. CTDs and optical backscatter sensors were carried on all these tests. To date Spray gliders have completed 38 missions spanning 294 days and completed 3018 profile cycles with the loss of one early vehicle for unknown reasons and severe damage to another in a collision with a surface vessel.

The data from all missions is stored at SIO on multiple media. Most missions were designed for engineering and are not of great scientific value. However, the data from the mission described in Figures 1 and 2, from the joint NOAA-ONR effort in AOSN-II, and from the initial crossing of the Gulf Stream are available at www.Spray.UCSD.edu.

Scientific Progress:
Scientific focus this year has been on three areas. Much work was done extracting descriptions of regional and basin-scale ocean circulation from profiling float deployments begun up to 14 years ago. Studies include descriptions of the subtropical North Atlantic subduction zone, enhanced carbon sequestration as the result of the Southern Ocean iron fertilization experiment, and the intermediate-depth circulation of (a) the Indian and South Pacific (based in part on CORC observations), (b) the South Atlantic (based largely on CORC observations), and (c) the subpolar North Atlantic:

3.8a. CORC: Drifter Observations and Analyses

by Pearn P. Niiler

PROJECT SUMMARY

a) Drifter Acquisitions and Enhanced Deployments in the Tropical Pacific:

This year SVP drifters were ordered from Technocean, Inc. (50) and Clearwater, Inc. (50). These were shipped to AOML and were deployed in the tropical Pacific between 20°N and 20°S, with 40 CORC and 60 ONR drifters being deployed into the region of the Luzon Strait to measure the seasonal inflow from the western tropical Pacific into the South China Sea (Fig. 1: Centurioni et al. 2003).

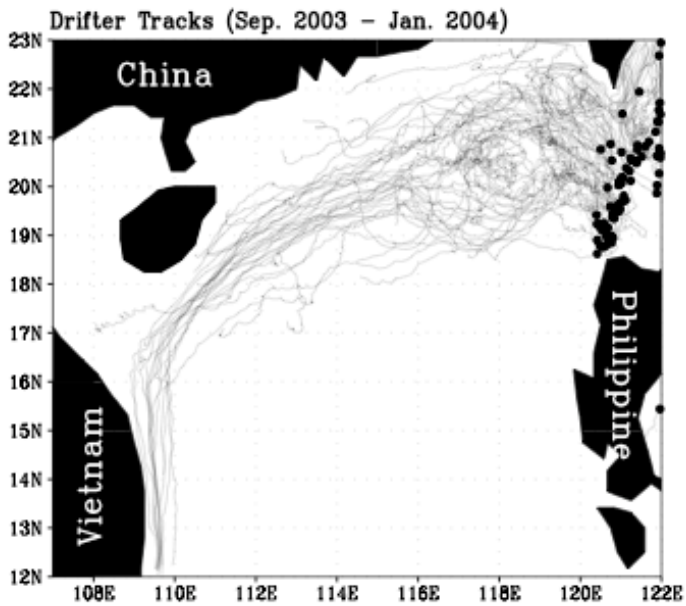


Figure 1. The SVP drifter tracks from the September 2003-January 2004 deployments into the Luzon Strait.

b) Attachment of MICROCAT Salinity Sensor to the SVP Drifter:

In the period 2000-2004, Sea Bird SEACATs were attached to 28 SVP drifter surface floats. These were deployed into the East China Sea in the August-September periods of each year to follow the Yangtze River out-flow during the Southwest Monsoon floods (Fig. 2). The technical objective of this development was to facilitate the SVP network as platforms for SSS observations that are stable to 0.02 psu for more than 300 days. NASA plans to call for the use of the North Pacific and Tropical Atlantic SVP drifter arrays for calibration and validation of the AQUARIUS SSS satellite that is to be deployed in late 2007. Further testing of the SEACATS, with and without pumped sensors will be done into the eastern North Atlantic in 2005 with the cooperation of the French Meteorological Service buoy tenders for deployments and recoveries.

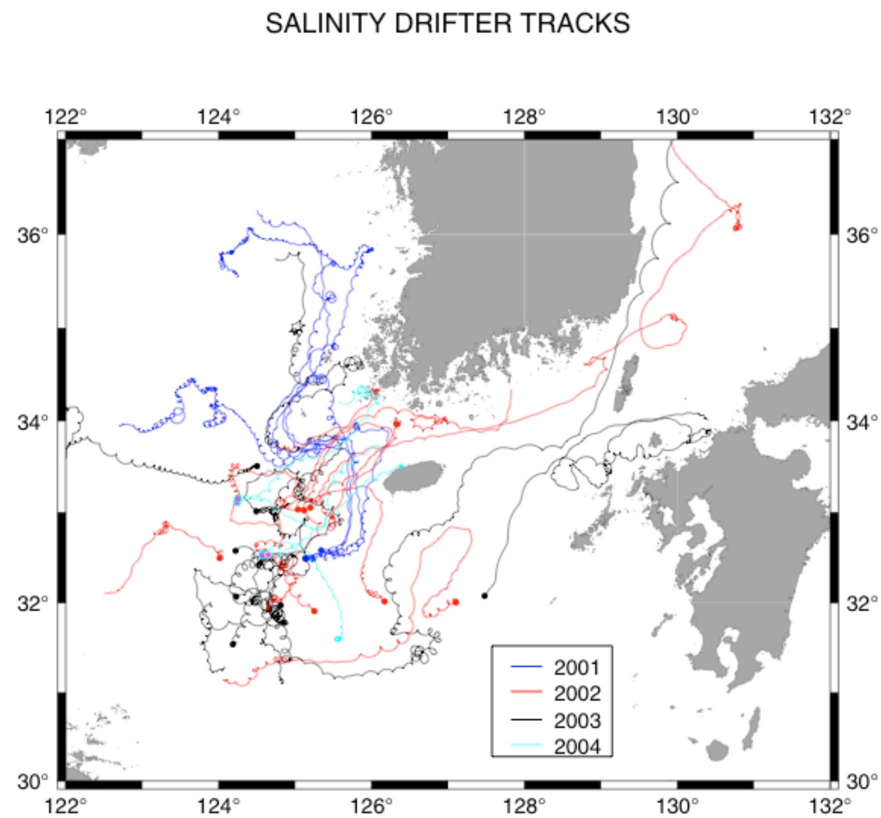


Figure 2. Drifter tracks from 2000-2004 (each year is different color) in the East China Sea with attached MICROCATs for SSS observations.

c) *Analysis of Southern Ocean CORC Observations*

In the period 1994-2000, CORC drifter observations were taken in the Southern Ocean. In partnership with members of the WMO operational meteorological services, these provided the impetus for deployment of a permanent array of about 200 SVP-B ("B" is for barometer) drifters south of 35°S. Analyses of these data have provided high spatial resolution maps of the Aghulas Current system along the east coast of South Africa and its seaward extension (Pazen and Niiler, 2003). Apparent in the Aghulas Extension are seven semi-permanent meanders. A theoretical explanation for these meanders can be found in the theory of steady, eastward flowing meandering jets (e.g., Robinson and Niiler 1967), as shown in Figure 3.

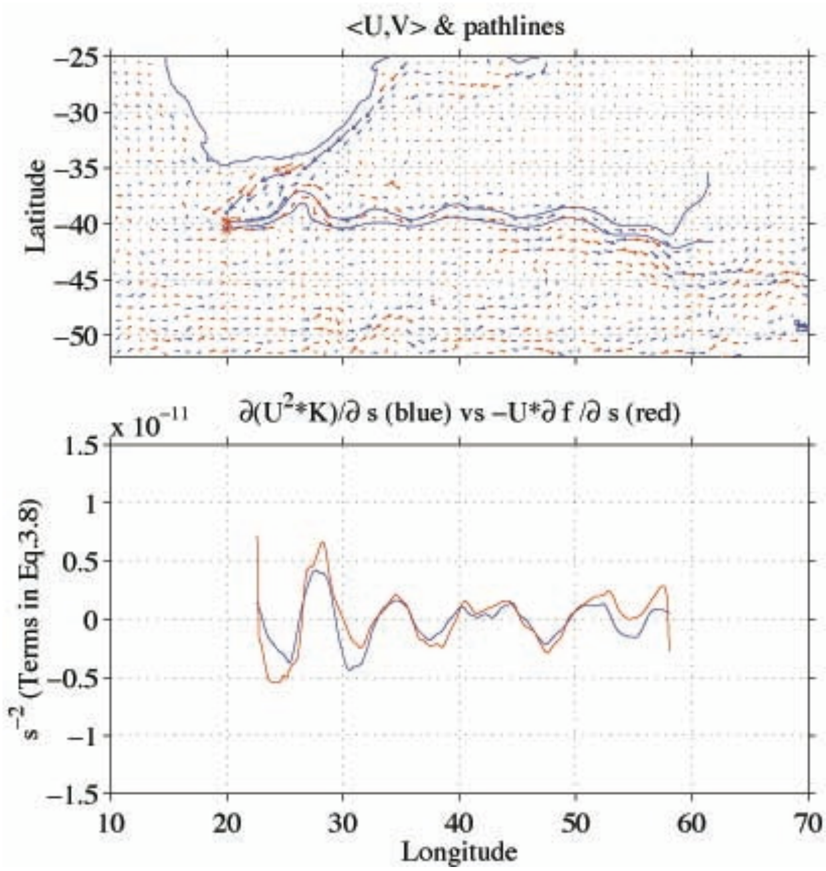


Figure 3. (a) Semi-permanent meanders in the surface current of the Aghulas Extension. The velocity data are an ensemble average of observations from 1978 to 2003 on 1/2 degree resolution, with arrows blue when a northward component of velocity is present.

(b) The time mean surface vorticity balance in the path-wise coordinate system along the time mean path very near the velocity maximum. The advection of relative vorticity (red line) is balanced by the advection of planetary vorticity (blue line) indicating that near the velocity maximum eddies are inefficient in providing for a vorticity transport convergence (courtesy of Dr. Pepe Ocheo 2004).

3.9a. CORC: High Resolution XBT/XCTD (HRX) Transects

by Dean Roemmich, Bruce Cornuelle, and J. Sprintall

PROJECT SUMMARY

Overview: Eddy-resolving boundary-to-boundary temperature (XBT) transects are collected on a quarterly basis along selected routes in the Pacific and Indian Oceans, as shown in Fig 1. Objectives are to measure annual and interannual fluctuations of temperature, salinity, and large-scale ocean circulation, including the variability of mass, heat and freshwater transports. These large-scale transports constitute the ocean's dynamic contribution to the climate system. The HRX sampling mode captures important elements of time variability in ocean circulation, transport, and property distributions that are missing from one-time hydrographic sections and from broad-scale XBT sampling. Since its beginnings in 1986, the HRX Network has resulted in a considerable body of original research, including studies of water mass properties and variability, ocean general circulation, heat transport variability, and equatorial dynamics.

HRX transects are usually carried out by a technician or scientist on board a commercial vessel, and consist of 0-800 m XBT temperature profiles at spatial intervals of 30-50 km in the ocean interior and 10-20 km in boundary regions. A number of additional activities are carried out by the ship riders, including:

- Sparse sampling with XCTDs to resolve large-scale T/S variability.
- Testing of the new 2000-m research quality T-12 XBT.
- Occasional deployment of Argo floats.
- Technical support for VOS IMET installations (R. Weller, PI).

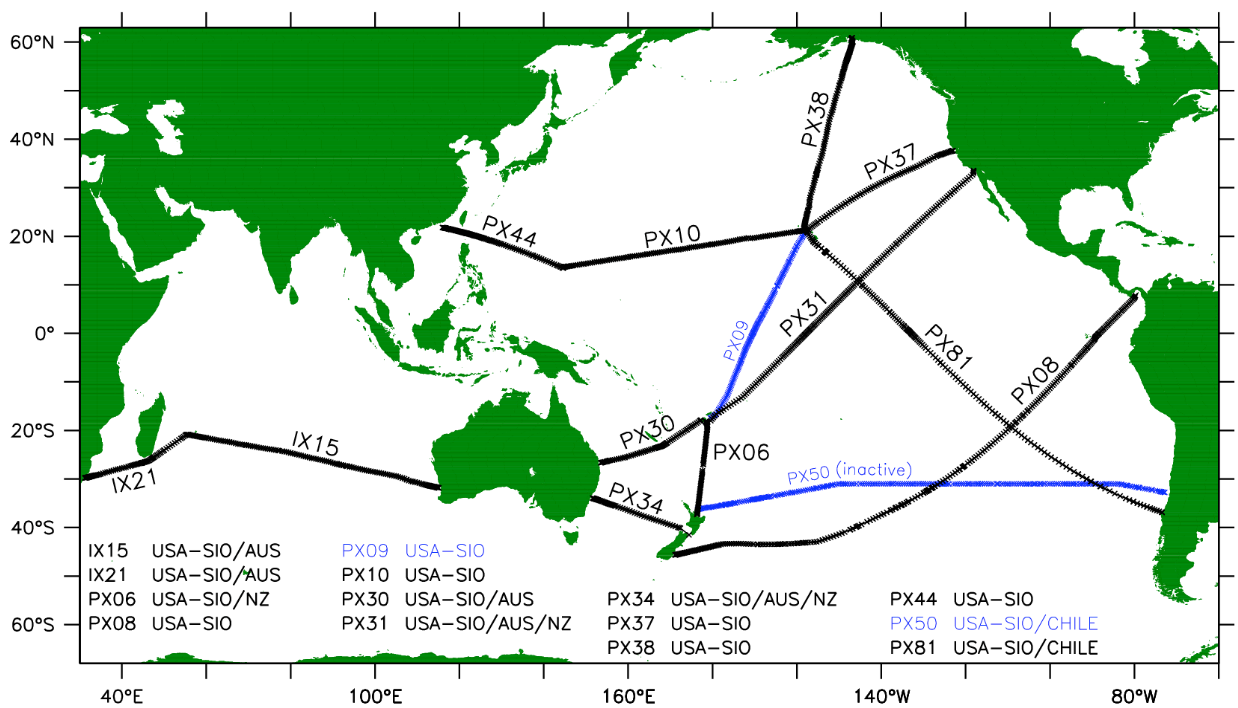


Figure 1: SIO HRX transects in the Pacific and Indian Ocean. PX30 and PX34 are carried out on an equal collaborative basis with CSIRO.

Role in the NOAA Program Plan for *Building a Sustained Ocean Observing System for Climate*: The HRX Network is a named element in the Program Plan *(Sect 6.4.)*. It directly addresses the Plan's objectives *(3) Document heat uptake, transport, and release by the ocean;* and *(4) Document the air-sea exchange of water and the ocean's overturning circulation.* In addition, it indirectly addresses objective *(1) Document long-term trends in sea level change,* by helping to understand the subsurface causes of steric sea level change.

Management: We participate in the Ship of Opportunity Implementation Panel (SOOPIP) under the JCOMMOPS Ship Observations Team (SOT). Overall priorities for the HRX networks were established by the Upper Ocean Thermal Review at the Bureau of Meteorology, Melbourne in August 1999, and are applied in managing the program.

Web site: All transects are displayed as temperature contour plots at http://www-hrx.ucsd.edu, and data are available for download from that site. Although HRX data are archived at NODC, they are not made available by NODC in the form of single-cruise transects. Since HRX data have high value as transects, the HRX web site referenced above provides them in that form.

Partnerships: The HRX program is a multinational collaboration involving scientists from the USA, Australia, Japan, Chile and New Zealand. The global HRX network began with a single transect, carried out by D. Roemmich and B. Cornuelle between New Zealand and Fiji in 1986. It was subsequently expanded to the ocean-spanning array shown in Figure 1, with an equivalent Atlantic HRX network carried out by NOAA/AOML with other international partners. Collaboration with the NOAA GOOS Center at AOML results in HRX data being transmitted in near real-time to the GTS as part of the NOAA SEAS system.

Climate Monitoring Principles: The HRX Program is managed in accordance with the Ten Climate Monitoring Principles.

FY2004 PROGRESS

The status and progress on HRX XBT transects in the Pacific and Indian Oceans in the last year is described below, with track locations shown in Figure 1. The report includes lines presently supported by NOAA and also lines proposed for NOAA support in the coming year. These lines are presently supported by an expiring NSF grant.

A summary of successfully completed transects for all lines during FY2004 is given in Table 1. The table also lists the starting year of HRX sampling along each line, and for comparison the number of successfully completed transects during the previous 5-year period. A "transect completion score" is calculated from the ratio of completed transects (up to 4 per year for each line) to nominal transects (4 per year). For FY04 the completion score is 45/48 = 94%, slightly less than for the previous 5-year period, 192/200 = 96%.

It also continues to be the case that ships carrying ship-riders produce better sampled transects (fewer and smaller gaps) and a higher percentage of good drops (mostly due to stern-launching rather than bridge-launching). In the SIO HRX program about 95% of probes produce good data.

Line	Year started	FY04 transects	Previous 5 years
PX37/10/44	1991	4/4/4	20/20/20
PX06/09 or PX06/31	1986/1987	4/3	19/19
PX81	1997	3	20
PX50 or PX08	1993	4	18[2]

PX38	1993	3	17
PX30[1]	1991	5	18
PX34[1]	1991	4	21
IX15/21	1994[3]	4/4	Note 3

Notes- 1: Collaborative with CSIRO Marine Research.
2: Shipping along PX50 was discontinued in April 2003 and is still dormant.
3: Shipping along IX15/21 was discontinued in 1995, resumed some years later.

Transects presently supported by NOAA
South Pacific line - (PX50) New Zealand-Chile, (PX08) New Zealand-Panama: Commercial shipping was discontinued on the direct route between Australia/New Zealand and South America (PX50) in mid-2003. The nearest alternate route is Auckland-to-Panama (PX08). We began HRX sampling along PX08 in January 2004. Four transects have been carried out aboard *PONL Mairangi*, in January, March, May, and September 2004. Our plan is to continue HRX sampling along PX08 unless shipping is resumed along PX50.

East Pacific line (PX81) Hawaii-Chile:
Three transects were carried out, on *NYK Nacre* in October 2003, and on *NYK Forestal Diamante* in May and August 2004. Shipping on the line is bulk cargo carriers trading between Japan and Chile. Individual ships do not remain in service for long, and the Hawaii port call for bunker fuel has been temporarily discontinued. Therefore, our ship-riders rode from Japan to Chile (PX25) in this year's cruises. We're evaluating the possibility of crew sampling along this line.

South Indian line (IX15/21) Fremantle-Mauritius-Durban:
Four transects on this newly implemented line were carried out aboard *MSC Federica* in December 2003, and March, July, and September 2004. Local logistical support is provided by CSIRO Marine Research. The ship sometimes follows a direct route from Fremantle to Durban (IX02) without advance notice.

Southern Ocean lines (AX22) Drake Passage, (IX28) Hobart-Dumont D'Urville:
We provide only technical/logistical assistance for AX22 (J. Sprintall, PI), which is sampled on a year round basis on the *R/V LM Gould*. IX28 is carried out by CSIRO Marine Research; we provide a small fraction of probes. During austral summer 2003-2004, six transects along IX28 were carried out aboard *L'Astrolabe*.

Transects proposed for NOAA support under Add Task 1 (presently NSF).
North Pacific line (PX37/10/44), San Francisco-Honolulu-Guam-Hong Kong:
Four transects were carried out aboard *Horizon Enterprise* in October 2003, and in January, May, and August 2004. The Enterprise is the longest serving ship in the HRX network, having been used along PX37/10/44 since its inception as an HRX line in 1991.

Northeast Pacific line (PX38), Honolulu-Alaska:
Three transects were carried out, one aboard *R/V Kilo Moana* in October 2003, and two aboard *Marine Columbia* in January and May 2004. There continues to be shipping along this route (mostly oil tankers), but the absence of scheduled repeating transits makes sampling somewhat problematic.

Central Pacific line (PX06/09) New Zealand-Fiji-Honolulu (or Los Angeles):
Four transects were carried out, beginning with the *Columbus Florida* in November 2003. That ship was taken offline, with no remaining ships along NZ-Fiji-Honolulu. Sampling was resumed

along NZ-Fiji-Los Angeles (PX06/30), which has been an alternate route over past years of our program, with transects aboard *Direct Tui* in April, July and August. The August XBT sampling was terminated in Fiji due to technical problems, and *Direct Tui* was subsequently taken offline. The next transect is planned for November using another *ANZDL* vessel.

Southwest Pacific lines (PX30) Fiji – Brisbane and PX34 (Wellington – Sydney):
These lines are carried out collaboratively with CSIRO. We provide most of the XBT probes while CSIRO provides most of the PX30 ship riders and the local logistical support. Sampling along PX34 is by the ship's crew. Five transects were carried out along PX30 aboard the *Forum Samoa,* in October 2003 and in January, March, June, and September 2004. Four cruises were carried out along PX34 aboard *ANL Progress* and *MSC New Plymouth*, in October 2003 and January, May and September 2004.

Other activities related to observations:

XCTD deployments: XCTD probes are deployed to measure large-scale variability in the T/S relation, with typically 12 – 18 probes used on a basin-spanning transect. Use of XCTDs is being slowly phased out as more regions become well populated with Argo floats. 134 XCTDs were deployed in FY2004.

T-12 XBT testing: We've carried out partially successful tests of the Sippican MK-12 XBT probe (2000 m, 20 kt, research quality), and are waiting on the manufacturer for additional probes.

VOS IMET systems: We provide logistical assistance to the WHOI IMET group for installation and maintenance of VOS IMET systems. There are presently two systems operating in the Pacific, on the *Horizon Enterprise* and the *Columbus Florida*.

Argo float deployment: HRX vessels are used for float deployment whenever floats are available for these lines. We provide logistical assistance and carry out the deployments.

MK21/autolauncher integration: Major software development work is nearly completed to convert the XBT autolauncher system from MS-DOS/Sippican MK-12 data acquisition to Windows/Sippican MK-21. This conversion is being done collaboratively with NOAA/AOML in order to produce fully compatible systems. We already collaborate with NOAA/AOML to provide real-time (GTS) transmission of data from HRX transects, and for shared use of equipment on joint use vessels.

Data distribution, availability, access and archive:
There are three pathways for HRX data distribution.

- GTS. All XBT profiles are immediately transmitted to the GTS using the NOAA SEAS system, except on vessels that do not have the necessary hardware (presently PX38, PX30). This is the primary conduit for use by operational centers and other near real-time users.
- Internet. Our web site (http://www-hrx.ucsd.edu) provides downloadable data in the form of 1 ASCII file per HRX transect, with 10-m vertical averaging. All data are stored and backed up at SIO. Requests for 2-m vertical resolution files, and for data too recent to have completed final QC, are handled on an individual basis.
- Data are passed to NODC to be archived and distributed. NODC/GTSPP is the primary data source.

Major research users of Pacific and Indian HRX data, in addition to SIO, include scientists at CSIRO Marine Research (Australia), NIWA (New Zealand), and Tohoku University (Japan).

Problems encountered:

- The most serious problem facing the HRX Network is the present “instability” of international shipping, somewhat exacerbated by increased global security measures. By “instability”, we mean that the average time spent by a vessel trading on a particular route has decreased markedly in the past decade. Ships and even routes now come and go, where they used to remain in place for many years. Along well-traveled routes, this is merely an inconvenience and expense, requiring laborious changes from ship-to-ship. Along lightly traveled routes, especially PX50 and PX81, it is a serious problem that threatens the viability of sampling along those lines. Increased security measures add to the difficulty by making it more likely that any particular vessel or owner will decline to carry scientific ship riders, thus further narrowing the list of prospective vessels.
- Conversion of auto-launcher software to SEAS compatibility operating under Windows/Sippican-MK21 has been slow and time-consuming (involving both SEAS and SIO personnel). As the changeover is not yet completed, we are still operating the autolauncher under MS-DOS/Sippican-MK12. MK12 data acquisition cards are no longer available or supported by Sippican, and are prone to frequent failure. During the past year this resulted in one transect being terminated (PX06/31). It is expected that this issue will be solved in the next 6 months with completion of the conversion

Research highlights:

HRX data are being incorporated in regional, basin-wide, and global analyses, as well as being used for comparison with data assimilation modeling results, such as ECCO.

- **Combining XBT and altimetric height data.** Willis et al. (2003) developed a new technique for combining XBT and satellite datasets, and applied it regionally in the southwestern Pacific. This was followed by a study of global interannual heat storage (Willis et al. 2004).
- **Regional to basin-wide studies of circulation and heat budgets** using HRX datasets are being carried out in the northeast Pacific (Douglass et al. (2004)), the southwest Pacific (Roemmich et al. 2004), and Drake Passage (Sprintall and Adams 2004).
- **Dynamical studies.** Willis (2004) used a quasi-geostrophic data assimilation model to study the structure and dynamics of propagating eddies in the North Pacific (following on Roemmich and Gilson, *Journal of Physical Oceanography* 2001). Work on this topic is ongoing.
- An especially noteworthy paper is the global analysis of ocean heat content and sea level variability, 1993 – 2003, by Willis et al. (2004).

3.10a. CORC: Development of an Underway CTD

by Daniel L. Rudnick

PROJECT SUMMARY

The development of the Underway Conductivity Temperature Depth instrument (UCTD) is motivated by the desire for inexpensive profiles of salinity from underway vessels, including volunteer observing ships (VOS) and research vessels. While expendable CTDs (XCTDs) do provide the needed salinity profiles at present, their cost limits how many can economically be used. The temperature-salinity (T-S) relationship is most variable in the mixed layer and seasonal thermocline where the ocean is in direct contact with the atmosphere. Deeper, climatological T-S relationships combined with XBTs are sufficient for observing the hydrographic structure that enters into momentum, heat and salt budgets. Thus, the design goal for UCTD was to obtain profiles deeper than 100 m at 20 knots (typical of a VOS). This goal has been surpassed, as we are able to profile to over 150 m at 20 knots, and to over 400 m at 10 knots.

The UCTD operates under the same principle as an XCTD. By spooling tether line both from the probe and a winch aboard ship, the velocity of the line through the water is zero, line drag is negligible and the probe can get arbitrarily deep. The challenge is to recover the probe, because the line velocity will then equal the ship speed, and line drag may become large. This has proven possible using a Spectra line commercially available for fishing. A number of advantages accrue because the UCTD is recovered rather than expendable. First, the cost per profile decreases as the probe is reused. Second, because the probe is recovered, sensors can be calibrated post-deployment, improving the quality of the observations. Third, the UCTD carries a pressure sensor so depth is measured more accurately than by the drop-rate equation typical for an expendable.

All of the components of the UCTD system have been designed, built, and used successfully. A description of the components follows. The probe has a four-electrode conductivity sensor, a thermistor, and a pressure sensor. Data from the sensors are logged at a frequency of 10 Hz by a Persistor microprocessor to solid-state memory. Between UCTD casts, data are downloaded to a laptop computer via a serial connection, the probe's battery is recharged, and the probe is initialized for the next cast. Deck gear consists of a davit, a winch, and a mechanism to rewind line onto the tail. The davit has a 4'x4' footprint, and can pivot and extend. The winch is a Penn International fishing reel equipped with a DC motor for fast recovery. The rewinding mechanism is driven by a variable speed motor, while level winding is accomplished with an adjustable pitch, reversing unit available commercially.

The UCTD operation is carried out easily and safely on an underway vessel, making no demands on vessel operators other than space on an aft quarter to put the equipment. The UCTD is deployed by dropping over the stern while letting the winch free spool (Fig. 1). As the fall rate is approximately 5 m/s, a 400-m profile takes 80 s. Assuming the ship is steaming at a speed of 5 m/s (10 knots), 400 m of line is pulled off the winch. The total of 800 m of line deployed at the conclusion of a profile takes roughly 15 min to recover with our current winch design. Recovery of the probe is accomplished by adjusting drag on the reel to be strong enough to pull in the probe but too weak to break the line, a simple matter as the probe weighs 10 lb, while the line breaks at over 300 lb. The probe is then pulled snug against a foam block attached over the line at the davit. Rewinding the tail and downloading data take about 10 minutes so that consecutive profiles can be done as rapidly as every 30 min.

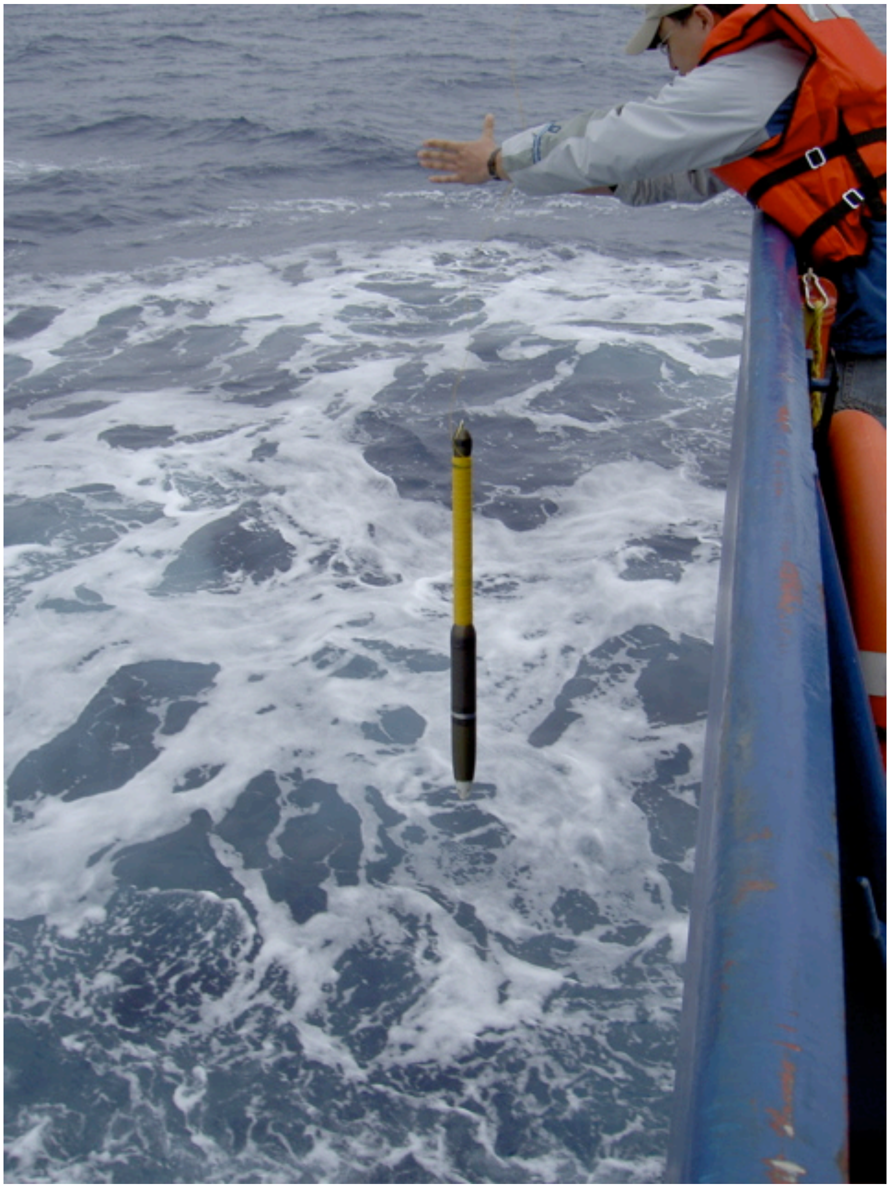


Figure 1. The UCTD falling into the water on deployment. The yellow on the tail is 400 m of Spectra line. Conductivity and temperature sensors are protected in the white nosepiece.

The UCTD directly contributes to the *Program Plan for Building a Sustained Ocean Observing System for Climate* by addressing the need for observations of upper-ocean salinity and temperature. These observations are needed to quantify the heat transport of the ocean, and air/sea interactions central to climate. The UCTD will fit naturally into the Ships of Opportunity Program (SOOP), and will increase the productivity of NOAA research vessels by providing the capability to make more underway observations.

As the UCTD has only this year begun to be operational, data are not yet being managed in cooperation with relevant international panels. As UCTD sees greater use, its data will be managed as are other temperature and salinity profiles in the ocean observing system.

UCTD was used on two cruises this year as part of the ONR-sponsored North Pacific Acoustics Laboratory (NPAL). Cooperating institutions included Woods Hole Oceanographic Institution and University of Washington.

UCTD is a new system with potential for improving the upper-ocean salinity database of the ocean observing system. UCTD is thus at step 1 of the 10 Climate Monitoring Principles: assessment prior to implementation. Should UCTD prove valuable, it will address point 7 by improving observations of relatively poorly observed upper-ocean salinity.

FY 2004 PROGRESS

The major accomplishment of the past year was the first operational use of the UCTD. We participated on an ONR-sponsored cruise whose purpose was to examine the effects of internal waves and density compensating thermohaline variability (sometimes called spice) on long-range acoustic propagation. The cruise resulted in over 160 successful UCTD casts (Fig. 2). The primary goal of the cruise was to deploy four acoustic moorings on a 1000-km path in the central North Pacific subtropical gyre. UCTD was used while the ship steamed at 10-13 knots between moorings. The resulting hydrographic section had a resolution of 10 km horizontally and 5 m vertically. The section clearly showed the effects of thermohaline variability on sound speed.

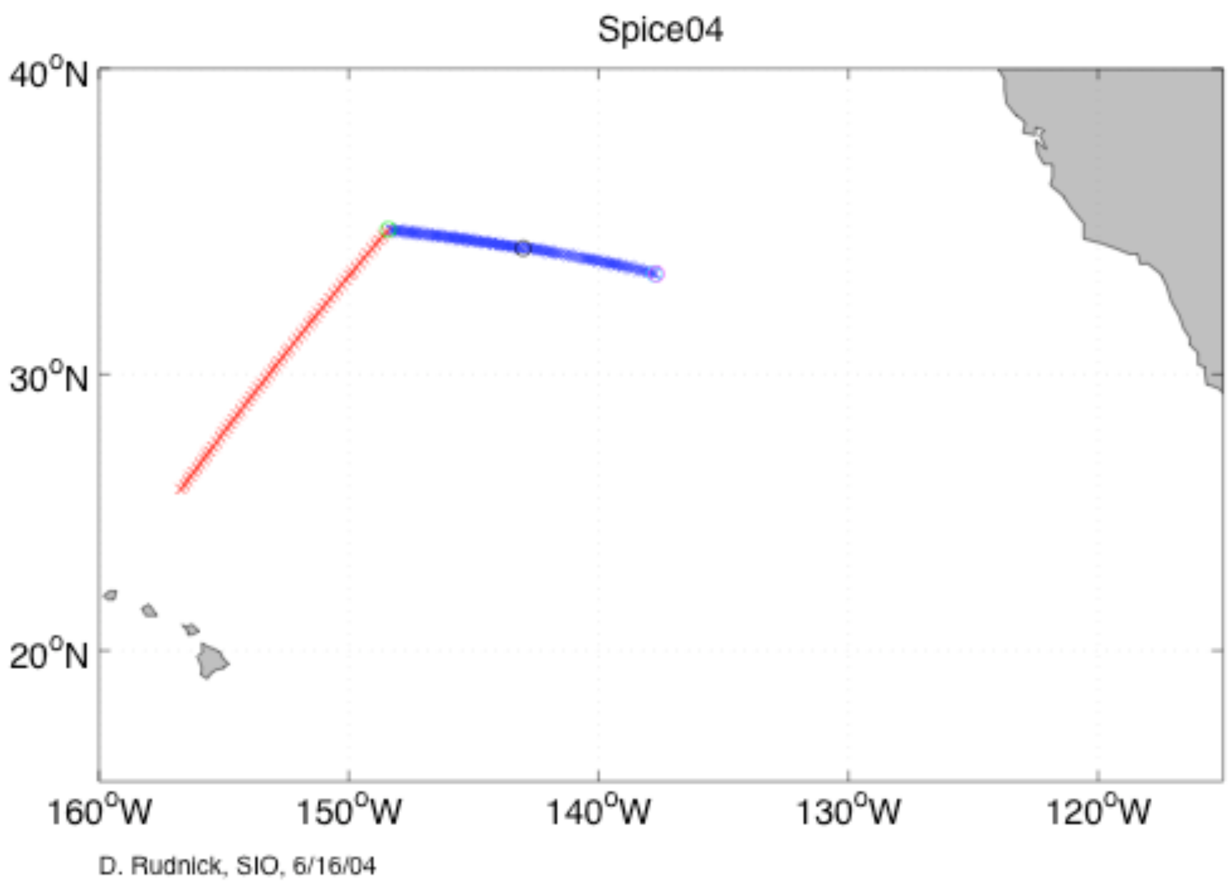


Figure 2. Locations of UCTD casts (x) and acoustic moorings (o) from the May-June NPAL cruise. The section marked by the blue crosses is shown below.

The section was done from east to west (Fig. 3). The changing depth of the profiles was directly related to ship speed. During the first quarter of the section ship speed was 11-12 knots, the second quarter 12-13 knots, and the second half 10 knots. Over the second half of the section the casts were mostly greater than 400 m, with the deepest ones greater than 430 m.

The summer mixed-layer depth of 20 m is evident in the figures as is the 100-150 m depth of the remnant winter mixed layer. Temperature-salinity features can be seen covering the depth of the winter mixed layer. Sound speed variability (changes as large as about 6 m/s over a horizontal distance of 10 km), and the resulting effects on acoustic propagation were the motivation for this experiment. The salinity minimum near the base of the winter mixed layer is a distinctive feature of this region.

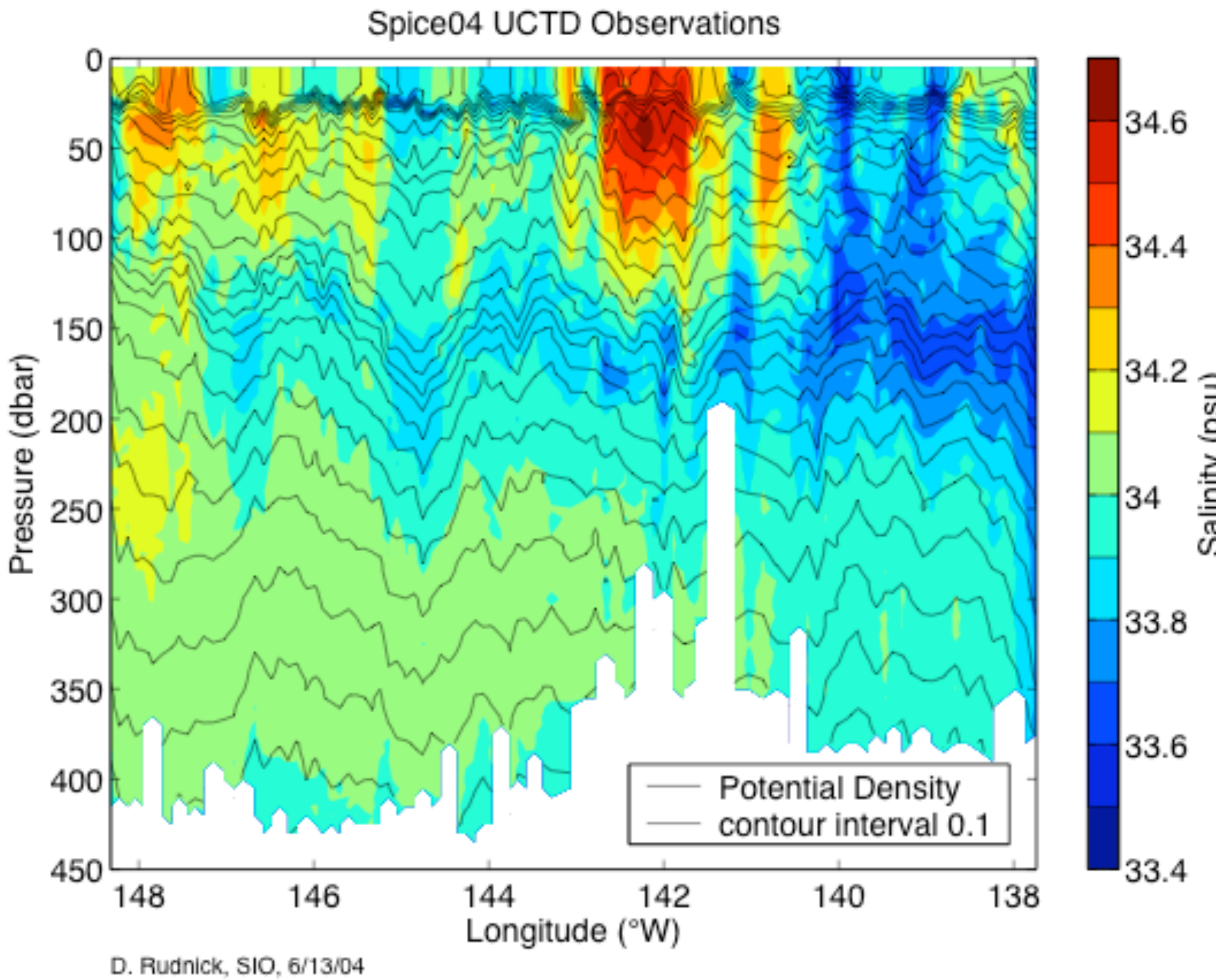


Figure 3. UCTD section of salinity (color image) and potential density (black contours) along the blue path in Figure 1.

UCTD was used again as part of NPAL during a cruise September-October 2004. Over 170 casts were completed during the first use of UCTD by operators other than the developers. This cruise marks an important step toward general use by the oceanographic community.

Data from the NPAL exercise are currently being processed to ensure accurate temperature and salinity. They will be archived at SIO and shared with interested scientists, especially others involved with NPAL. A major issue is the stability of the conductivity sensor.

3.11a. CORC: Lagrangian Salinity Profiling: Evaluation of Sensor Performance

by Raymond W. Schmitt

PROJECT SUMMARY

Principle investigator Schmitt has long been concerned with the challenge of assessing the strength of the hydrologic cycle over the ocean (Schmitt et al. 1989; Schmitt 1995). One important indicator of the water cycle is the salinity structure of the upper ocean (Schmitt and Montgomery 2000). This project focuses on instrumentation used to measure salinity on autonomous vehicles.

A basic need in *Building a Sustained Ocean Observing System for Climate* is reliable measurement technology and we are here focused on the quality of oceanic salinity instrumentation. Under CORC sponsorship we have advanced automated salinity measurement technology by working with Falmouth Scientific, Inc. (FSI) to improve their conductivity cell performance and assist in development of their "Excell" Float CTD. This work has helped to address problems with present instrumentation and provide diversified technology sources for salinity measurements within the ARGO float program. Early versions of the Excell were tested extensively for electronic performance and tuned to have proper dynamic response. Later models are performing much better than initial versions. Several FSI-equipped SOLO floats were deployed in the eastern tropical Pacific last year as part of the CORC/ARGO array.

Considerable effort has also gone into studies of the dynamic response of the sensors. Dynamic response is always a concern with salinity measurements from moving sensors, as temperature and conductivity cells inevitably have different response times, with different speed dependencies. This leads to an error in the calculated salinity which can be significant in strong thermoclines, and leads to subtle errors elsewhere. Salinity spiking and density inversions from SeaBird CTD equipped floats in ARGO has been a noticeable problem in some areas (G. Johnson, personal communication). Salinity spikes can be avoided if the dynamic response characteristics of temperature and conductivity cells are understood and adjusted for prior to calculation of salinity. This is an especially important issue for profiling floats as transmission of raw data is impractical and data reduction must be done on-board.

As this project seeks to improve the instrumentation at the basis of the growing climate monitoring system it certainly adheres to the philosophy of the 10 climate monitoring principles.

FY 2004 PROGRESS

In order to address the dynamic response problem we have constructed a special double-diffusive interface tank capable of long-term maintenance of a very sharp temperature/salinity step (Schmitt et al. 2004). Traversing the CTD through the interface reveals the sensor mismatches and allows development of an appropriate filter to optimize the accuracy of the salinity calculations. This has been done for the Excell float CTD. Figure 1 shows the dynamic response tank we are using for these tests. A new speed control mechanism was recently installed for tests of the SeaBird pumped CTD.

Research Highlights. Dynamic response testing of the SeaBird has recently been completed and a rather complex response function revealed. Figure 2 shows average scaled conductivity and temperature data from 11 such trials. Eleven plunge tests were averaged to account for the random timing between the slow Sea-Bird sample rate and the passage through the interface. Issues that can be identified in this type of plot are: 1. the relative placement of the temperature and conductivity probes, 2. the time constant of the temperature probe, and 3. the thermal mass of the conductivity cell. In addition, there appear to be electronic drift issues that complicate the development of a suitable correction algorithm. A correction algorithm for implementation on board the float is under development.

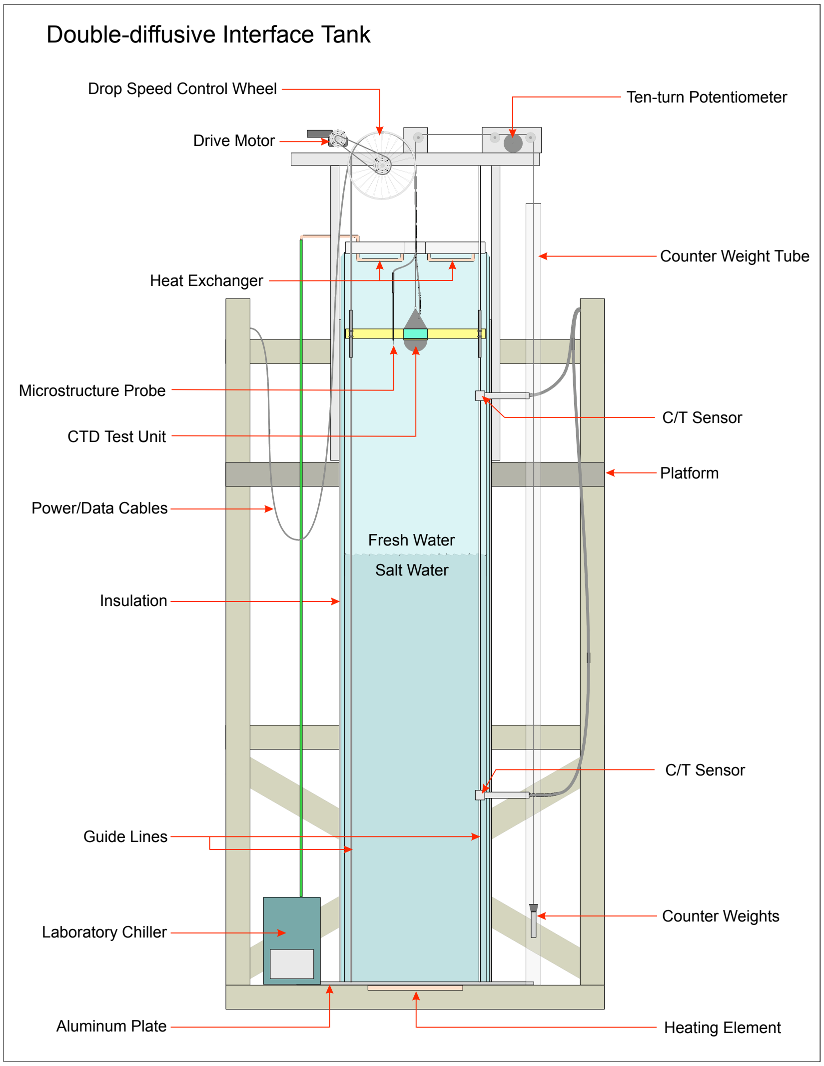


Figure 1. The double diffusive dynamic response tank used for tests of float CTDs. The 3 ft diameter pipe is 15 ft deep with a aluminum plate bottom. A heating element drives convection in the lower salty water and a heat exchanger cools the top of the upper fresh water. A computer controlled winch lowers the instruments through the sharp interface at a set speed. Sensors monitor the temperature and salinity of the mixed layers.

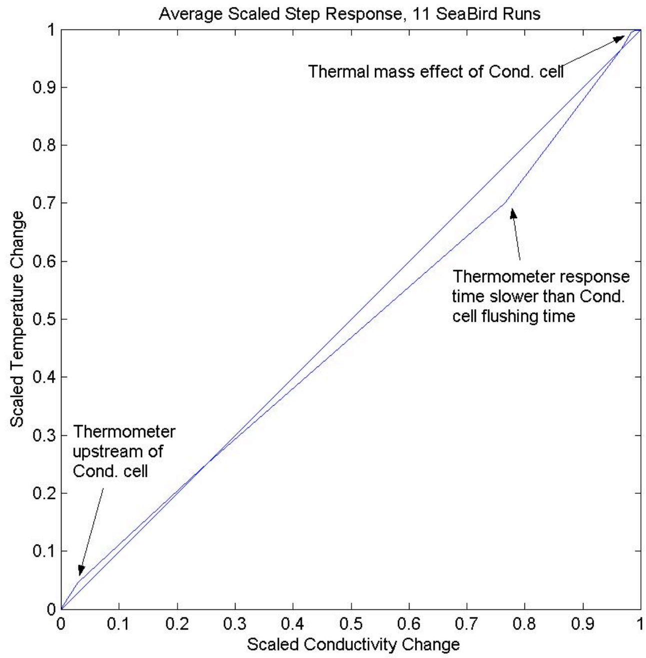


Figure 2. The average scaled step response from 11 plunges of the Sea-Bird float CTD through the double diffusive interface. The fall speed was 10 cm/sec and only data from the moving portion of the plunge were used. The instrument starts in the cold-fresh upper layer (0,0) and traverses to warm fresh (1,1). The deviation of the data from a straight line is indicative of lag and response time issues as shown.

3.12a. CORC: Observations of Air-Sea Fluxes and the Surface of the Ocean

by Robert A. Weller, Frank Bahr, and David S. Hosom

PROJECT SUMMARY

Central to present efforts to improve the predictability of climate is the need to understand the physics of how the atmosphere and ocean exchange heat, freshwater, and momentum and, in turn, to accurately represent that understanding in the models to be used to make predictions. At present, over much of the globe, our quantitative maps of these air-sea exchanges, derived either from ship reports, numerical model analyses or satellites, have errors that are large compared to the size of climatically significant signals. Observations made using the IMET technology on the Volunteer Observing Ships on long routes that span the ocean basins are essential to providing the accurate, in-situ observations needed to:

1) identify errors in existing climatological, model-based, and remotely-sensed surface meteorological and air-sea flux fields,
2) to provide the motivation for improvements to existing parameterizations and algorithms,
3) to provide the data needed to correct existing climatologies, and
4) to validate new model codes and remote sensing methods.

AutoIMET was developed by the Woods Hole Oceanographic Institution to meet the need for improved marine weather and climate forecasting. It is a wireless, climate quality, high time resolution system for making systematic upper ocean and atmospheric measurements. This interfaces to the NOAA SEAS 2000 (Shipboard Environmental (Data) Acquisition System) that automatically receives meteorological data (from the AutoIMET) and sends in automated one hour satellite reports via Inmarsat C. This system will document heat uptake, transport, and release by the ocean as well as the air-sea exchange of water and the ocean's overturning circulation.

Note that descriptions, technical information and data from the several VOS being serviced are posted on the site: http://uop.whoi.edu/vos/. Data (plots) are available for all ship sets.

Data (numbers) are available via anonymous ftp for the last data set only: ftp.whoi.edu/pub/users/fbahr/VOS. If data from previous times are desired please contact Frank Bahr at: fbahr@whoi.edu.

There is a link to the site: http://frodo.whoi.edu where there is detailed information on the AutoIMET and ASIMET modules. Instrument design questions can be addressed to Dave Hosom at: dhosom@whoi.edu.

Ship selection and interface to the NOAA SEAS system is via AOML. There is ongoing cooperation with Scripps via the CORCIII program on ship scheduling as well as Southampton Oceanography Centre (SOC) of Southampton UK on Computer Flow Dynamics (CFD) for evaluation of the flow turbulence around the ship and its effect on the sensor placement. Some logistic support is provided by the Southern California Marine Institute on ship turnarounds. There is ongoing cooperation with the Atlantic Marine Ocean and Atmosphere Laboratory (AOML) in Miami on the Atlantic VOS program. There is also ongoing cooperation with many sensor manufacturers and the VOS people at the German Weather Service (Deutscher Wetter Dienst) in Hamburg Germany.

This project is managed in accordance with the Ten Climate Monitoring Principles.

FY 2004 PROGRESS

The CORCIII program supports two ships in the Pacific and had the following activities:

Horizon Enterprise

Columbus Florida

This is for the period 1 October 2003 through 30 September 2004 on a program to improve the surface meteorological and sea surface temperature observations made by U.S.VOS as described by WHOI Proposal Serial No. PO10731.01. The actual accomplishments at this point in time match the goals and objectives of the proposal. During this period we continued to build the program to attempt to improve the observations made by the U.S. Volunteer Observing Ship (VOS) fleet and to collaborate with VOS Expendable Bathythermograph (XBT) investigators on testing and evaluating data from modules developed during the program.

December 2003. ASIMET modules were removed and an AutoIMET system installed on the Horizon Enterprise in Oakland CA.

December 2003. The AutoIMET system was turned around on the Columbus Florida in Long Beach, CA. The system that was removed had sustained serious sea damage in that the wind sensor was rearranged at the top of the bow mast and the HullCom (acoustic modem for SST) was flooded.

The HullCom was repackaged in an o-ring sealed titanium housing for re-installation. This packaging is the standard for use on ocean buoys using IMET. One set of ASIMET modules was converted to the AutoIMET configuration. Note that with the 3 new and 3 conversions all 6 systems are in the AutoIMET configuration to support 4 ships.

February 2004. Computer problem serviced in Hawaii on the Horizon Enterprise.

March 2004. The power system on the Columbus Florida was converted from batteries to an all a.c. system. Note that the power unit was located near the SST and the HullCom was removed. The ship officers were very supportive and provided bulkhead stuffing tubes and power interface.

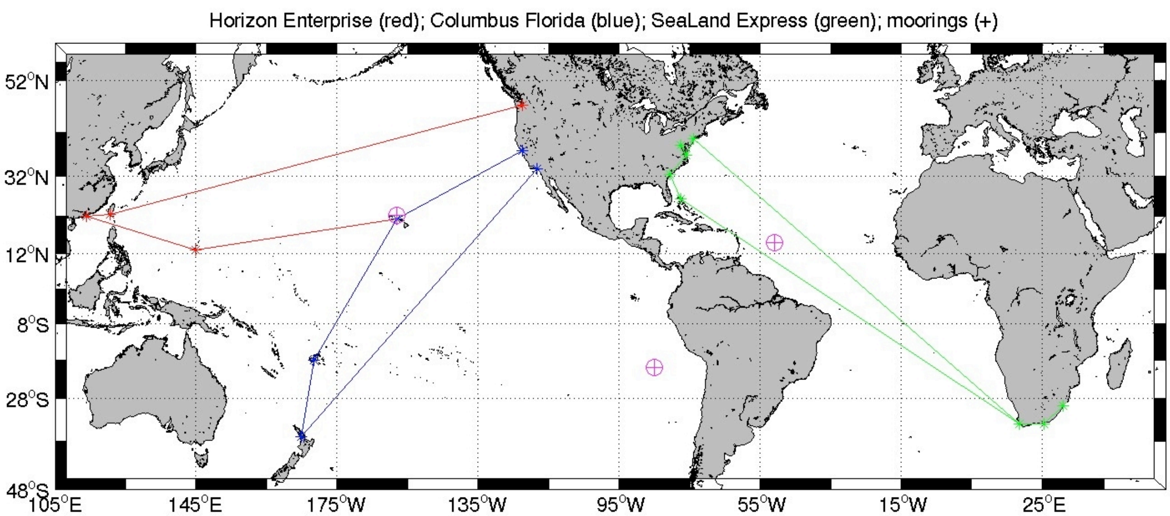
April 2004. Annual Office of Climate Observation (OCO) Workshop and the 2nd High-Resolution Marine Meteorology (HRMM) Workshop in Silver Spring, MD.

April 2004. Turnaround of AutoIMET on the Horizon Enterprise in Oakland, CA.

May 2004. Turnaround of AutoIMET system on the Columbus Florida in Long Beach, CA.

Sept 2004. Turnaround of AutoIMET on the Horizon Enterprise in Oakland, CA. The ship has provided a bulkhead fitting that will permit the SST to operate on a.c. power and remove the batteries and acoustic modem (HullCom). This improves reliability, gives SST every 6 minutes to SEAS, and reduces the cost of operation (no batteries).

ROUTE MAP



Note the Ocean Monitoring Stations (circle with cross) being operated by WHOI.

The CFD (Computer Flow Dynamics) work continues at Southampton Oceanography Centre on the feasibility of CFD on generic VOS.

3.13a. Flux Mooring for the North Pacific's Western Boundary Current: Kuroshio Extension Observatory (KEO)

by Meghan F. Cronin, Christian Meinig, and Christopher L. Sabine

PROJECT SUMMARY

Overview:

As a NOAA contribution to the global network of ocean time series reference stations, an air-sea flux buoy was deployed in the Kuroshio recirculation gyre at 144.5°E, 32.3°N in June 2004. During this first deployment (June 2004-June 2005), the buoy is monitoring air-sea heat, moisture, and momentum fluxes, and surface and subsurface temperature and salinity. In June 2005, we plan to include a pCO_2 sensor to monitor carbon flux (see Sabine Add-Task). The site is within the NSF-funded Kuroshio Extension System Study (KESS) domain and KESS has provided ship time, equipment and personnel for mooring operations. In addition, KESS will provide important oceanic data for understanding processes affecting the heat content and strength of the recirculation. Collaborations with Japanese PIs have begun and a partnership for developing and maintaining the KEO array appears to have broad support.

Scientific Rationale:

As with other western boundary currents, the North Pacific's western boundary current has some of the largest air-sea fluxes found in the entire basin. It is one of the largest sinks of carbon in the North Pacific, has the characteristic maxima lobes of latent, sensible, and net surface heat loss, and is co-located with the Pacific storm track. As the northward flowing Kuroshio current leaves the Japanese coast, it carries warm water at nearly 140 million cubic meters per second (i.e. 140 Sv) eastward into the North Pacific, where it is termed the Kuroshio Extension (KE). Wind-driven Sverdrup transport accounts for about a third of this transport; the other ~90 Sv is due to a tight recirculation gyre whose size varies on seasonal-decadal time scales (Fig. 1). As cold dry air comes in contact with the warm KE and recirculation water, heat and moisture are extracted from the surface, resulting in deep atmospheric convection and rainfall (Fig. 2). This heat and moisture are then carried poleward and eastward by the Jet Stream's storm track. In late-winter, surface water in the KE recirculation region is subducted into the permanent thermocline to form *Subtropical Mode Water*. As mode water is formed, carbon is sequestered. Large dust clouds blowing eastward off Asia are visible in satellite images and can be traced all the way across the Pacific basin. Asian dust is rich in iron and other nutrients. At present we have no in situ information on how the carbon cycle's biological pump is affected by the passage of these clouds.

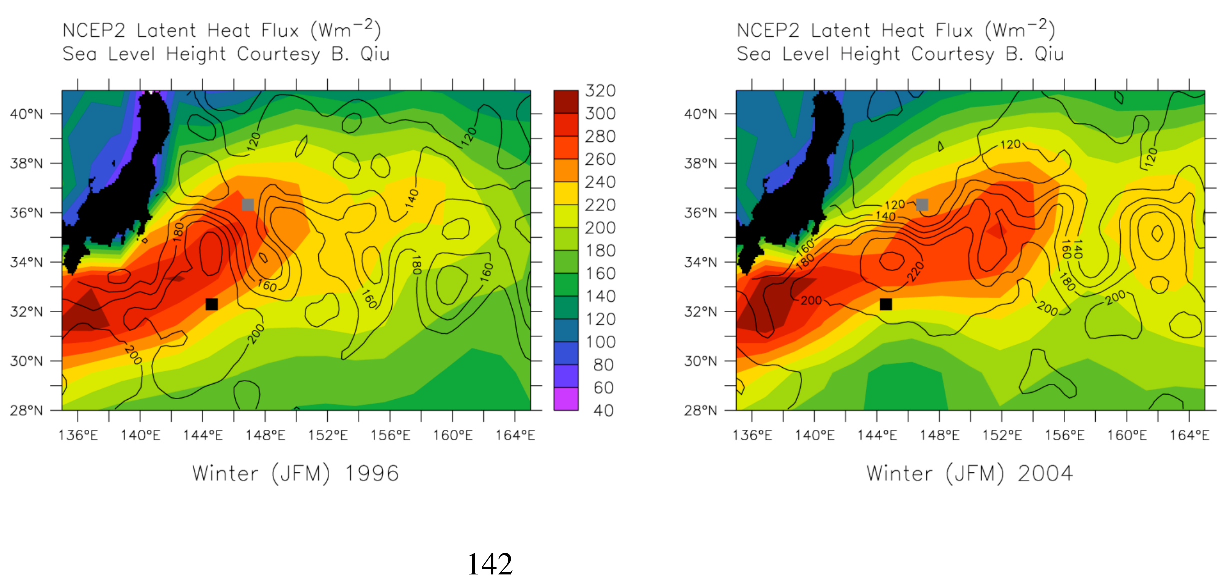


Figure 1. Wintertime (January-March) latent heat flux and sea level height in the Kuroshio Extension region during 1996 (left) and 2004 (right). The KEO site is indicated by a black square. Sea level height contours can be interpreted as surface geostrophic streamlines of flow. The KEO-2 site is indicated by a gray square.

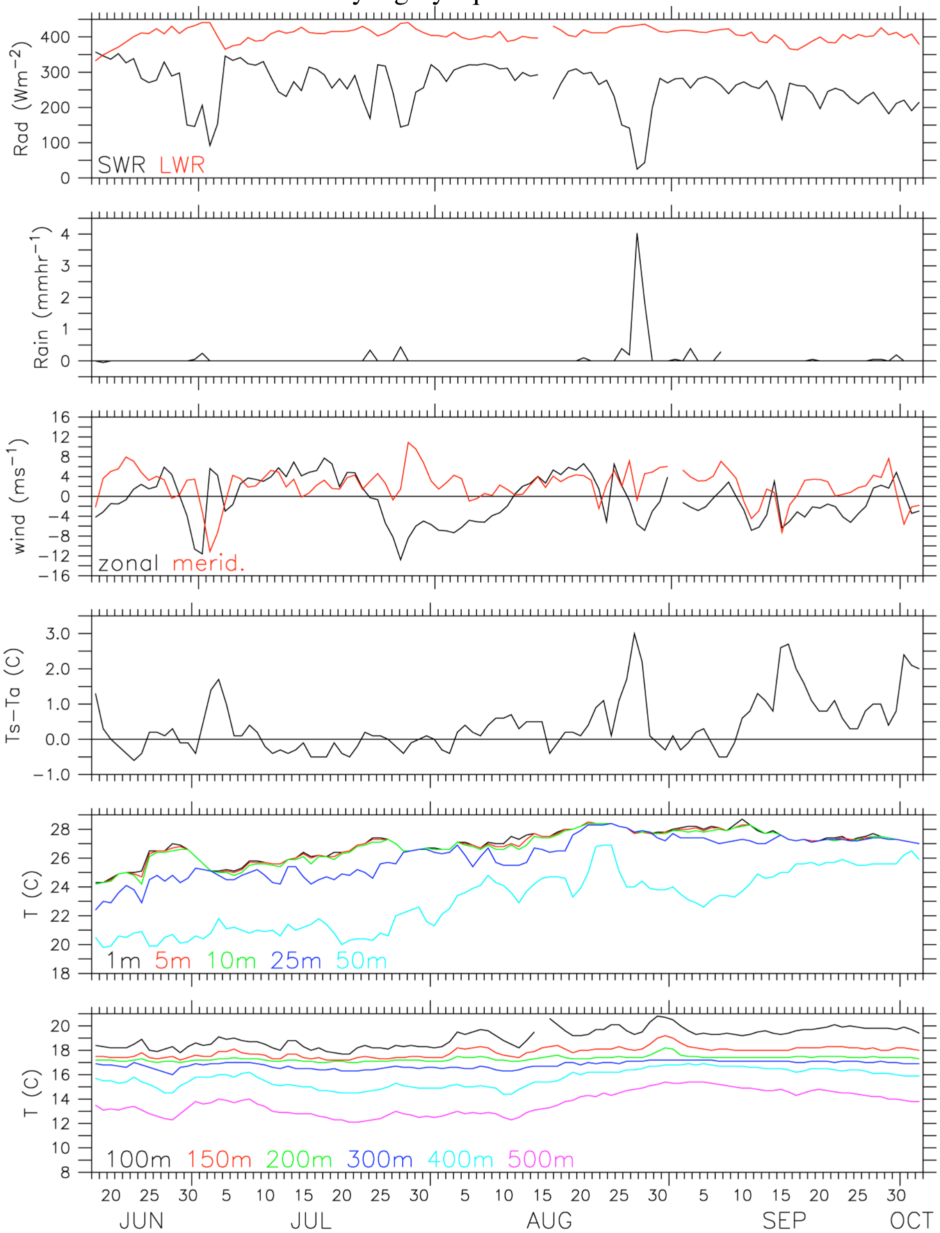


Figure 2. KEO telemetered daily-averaged data during 2004.

The KEO site is at 144.5°E, 32.3°N on the southern side of the Kuroshio Extension in its recirculation gyre. The Partnership for the Observation of the Global Oceans (POGO) has recommended the Kuroshio Extension as a site for an Ocean Sustained Interdisciplinary Timeseries Environmental Observatory (OceanSITES). With surface currents of almost 3 knots (~150 cm/s), a typically rough sea state, and lying in the Jet Stream's storm track, the KE is an extremely difficult region to observe. Ships have been the traditional platform for observing air-sea interaction in western boundary currents. However research cruises typically last no more than a month or two, and measurements from research ships and vessels of opportunity are biased towards good weather. To survive the strong currents, the surface mooring must be carefully engineered to have extremely low drag. Mooring design analyses have been performed by engineers at PMEL (co-PI Meinig is PMEL lead engineer) and vetted with scientists and engineers at WHOI and JAMSTEC. The mooring is slack-line with a scope of 1.4, and has minimal subsurface instrumentation during the first year. To minimize the risk involved in this project, the first year deployment is relatively modest and highly leveraged. Furthermore, the mooring is carrying a load-cell and telemetering engineering data, as well as the physical data. Although historically the KE has meandered over the site location, the KE appears to have entered a quasi-stable straight path, with axis north of the site (Fig. 1). Although we are confident that the buoy will survive the winter, in the event that the buoy sinks, we will have the engineering data to understand the tolerance limits of the mooring. Western boundary flux mooring will undoubtedly require ongoing engineering. We are eagerly awaiting wintertime when air-sea interactions intensify.

Addressing NOAA's Program Plan:
The KEO buoy is a contribution to the network of Ocean Reference Stations in a key region for air-sea interaction and therefore directly addresses the sixth element of the Program Plan for Building a Sustained Ocean Observing System for Climate (Ocean Reference Stations). With a Carbon Flux sensor this project would directly address the eighth element "Ocean Carbon".

Management in Cooperation with International Panels:
The KEO site has been endorsed by the International Time Series Science Team (co-chaired by R. Weller), which reports to the Ocean Observations Panel for Climate (OOPC). The two primary international ocean carbon research programs are the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) and the Surface Ocean Lower Atmosphere (SOLAS) programs. Both groups strongly recommend carbon time-series measurements and are very supportive of NOAA's efforts to develop a global pCO_2 mooring network. The KEO mooring is an important part of that effort. Time-series carbon measurements are also a key element of the United States research programs like the Ocean Carbon and Climate Change Program (OCCC).

Responsible Institution:
NOAA Pacific Marine Environmental Laboratory is the responsible institution for this project.

Websites:
KEO website: http://www.pmel.noaa.gov/keo/

Partnerships:
The KEO project has several strong partners. The KEO buoy is an element of the OceanSITES network of reference sites and therefore is partners with other buoy programs in the network (e.g., stratus, NTAS, HOT, TAO/TRITON,…). TAO and the NSF-funded Kuroshio Extension System Study (KESS) are particularly close working partners. The buoy was originally purchased under the now-complete NOAA OGP funded TAO-Eastern Pacific Investigation of Climate (EPIC) project. Professional staff supported by the KEO project are drawn from the pool of professional staff that participate in the TAO program. Located within the KESS array and within 10 km of N. Hogg's subsurface profiler mooring, the KEO buoy is contributing scientifically to the KESS experiment. KESS in turn has provided ship time, technicians and equipment for mooring operations. After the final KESS recovery cruise in June 2006, it is hoped that ship time will be provided through JAMSTEC. Partnership with JAMSTEC during FY04 resulted in a science meeting at JAMSTEC, "KESS and Beyond" co-organized by Drs. Cronin and Ichikawa. Subsequently, Prof. Kubota has asked Cronin to collaborate on a project titled "KESS-flux" and

Drs. Ichikawa, Konda, and Tanimoto have a proposal pending in which PMEL would be contracted to deploy a buoy, much like KEO, across the jet from the KEO site, either upstream or downstream. This partnership is a step towards our goal of having an array of buoys that would monitor the patterns of atmosphere and ocean exchanges in this dynamic region. During FY05, we hope to add a pCO_2 flux sensor to the suite of sensors. With this the carbon measurement, the KEO project would become a partner to NOAA's Global Carbon Cycle Program. This partnership is represented by co-PI Sabine.

Monitoring Principles:
The project is managed in accordance with the Ten Climate Monitoring Principles.

FY2004 PROGRESS

KEO buoy:
FY2004 was the first year of the KEO project. During FY2004, a buoy from the now-complete TAO-EPIC project, was retrofit into a more robust platform. The mooring was redesigned to be a slack-line mooring with 1.4 scope and 500 m of fairing. A load cell and GPS transmitter were purchased to monitor the tensions and location of the buoy. To survive winter storms, the standard RM Young vane and propeller wind sensor was replaced with a sonic anemometer. The full suite of meteorological measurements on the first-deployment of the KEO buoy includes: wind speed and direction, air temperature, relative humidity, rainfall, and solar and longwave radiation. Surface and subsurface measurements include sea surface temperature and salinity at 1 m, subsurface temperature at 11 depths down to 500 m, subsurface salinity at 8 depths down to 400 m, and pressure at 100 m, 300 m, and 500 m.

The KEO buoy was shipped to Yokohama, Japan and deployed from the KESS mooring cruise aboard the R/V Thompson with N. Hogg (WHOI) as Chief Scientist in June 2004. The mooring operation was led by PMEL mooring technician S. Kunze and aided by 3 WHOI mooring technicians, as well as other KESS and ship personnel. M. Cronin helped stage the buoy in Yokohama prior to deployment, but did not go on the cruise. During staging, M. Cronin and H. Ichikawa held a "KESS and Beyond" science meeting at JAMSTEC that drew together KESS scientists and climate scientists from throughout Japan.

In addition to the "KESS and Beyond" meeting, there have been several informal meetings with Japanese investigators at the CLIVAR2004 conference in Baltimore, MD, and at the AMS air-sea interaction conference in Portland ME. These discussions have culminated in a JAMSTEC proposal submitted in late September 2004 by Drs. Ichikawa, Konda, and Tanimoto to deploy a PMEL KEO buoy in the KE in fall 2005. This effort represents a clear intention by JAMSTEC to form a partnership with PMEL to build a Kuroshio Extension Observing array. Ultimately the success of the KEO project will depend upon the formation of such a partnership and thus this JAMSTEC proposal represents a major step forward for the KEO project.

Data Management:
Daily-averages of nearly all data (surface and subsurface) are telemetered to PMEL and made available in near-real time from: http://www.pmel.noaa.gov/keo/data.html
Because the KEO array is at this time an array of one buoy, the data are being withheld from the Global Telecommunications System (GTS) so that they can be used as an independent validation in comparisons with satellite and numerical weather prediction (NWP) fields. This decision will be reviewed periodically. High-resolution surface and subsurface data will be made publicly available through the KEO website within 6 months of recovery.

KEO data has had an excellent data return, with greater than 99% data return for the surface meteorological measurements. Due to transmission failure from the 75 m module and several random transmission drop-outs, the overall data return for KEO telemetered data is 93%. When data are recovered from internal memory, the overall data return may increase.

Research Highlights:
Within days of the deployment, remnants of super typhoon Dianmu passed over the buoy and can be seen in the KEO data (Fig. 2). Likewise, the eastern edge of typhoon Megi passed over the KEO site in late August, resulting in nearly 10 cm of rainfall in one 24-hour period and a 24-hour average solar radiation value of 25 Wm^{-2}. Large air-sea temperature differences can also be seen in the data. Heat fluxes associated with cold-air outbreaks can contribute to explosive cyclogenesis, yet are often poorly modeled and can contribute to systematic biases in seasonal and climatological NWP flux estimates. For this reason, researchers at ECMWF (Beljaars 2004, personal communication) and elsewhere are very interested in tracking cold-air outbreaks in the KEO data. Although it is early for detailed analyses, already KEO data are being used to compute air-sea heat fluxes for comparisons with the J-OFURO satellite derived flux products (Kubota 2004, personal communications). Kubota has a proposal submitted to Japan's Ministry of Education, Culture, Sports, and Technology to collaborate with Cronin on "KESS-fluxes". As can be seen in Fig. 1, the Kuroshio Extension appears to have entered into a stable path-state. During 2003 and 2004 no large meanders were observed (Qiu 2004, personal communication). The KEO site is well placed for investigating the role of the recirculation gyre heat content and air-sea heat exchanges in maintaining the quasi-stable path.

3.14a. High Resolution Climate Data From Research and Volunteer Observing Ships

by C. W. Fairall

PROJECT SUMMARY

This project involves the measurement of direct high-resolution air-sea fluxes on two cruises per year and the development of a roving standard flux measuring system to be deployed on a series of NOAA and UNOLS research vessels to promote the improvement of climate-quality data from those platforms. An adjunct task is maintenance and operation of the C-band scanning Doppler radar and the stabilized wind profiling radar on the NOAA ship *Ronald H. Brown*. Because buoys and most ships and satellites rely on bulk methods to estimate fluxes, another aspect of this project is the use of direct measurements to improve the NOAA/COARE bulk flux algorithm. One cruise is the annual TAO buoy tending cruise to 95° and 110°W on the *Ronald Brown*, which occurs every fall. The second cruise, which also occurs in the fall, is the annual excursion to turn around the Stratus climate buoy at 20°S, 85°W. A full suite of direct, inertial-dissipation, and bulk turbulent fluxes are measured along with IR and solar radiative fluxes, precipitation, and associated bulk meteorological properties. This effort represents a partial transition of research from the OGP CLIVAR PACS program to operations under the Climate Observation Program (COP).

The project development is the result of a recent NOAA-sponsored workshop on high-resolution marine measurements (Smith et al. 2003, *Report and Recommendations from the Workshop on High-Resolution Marine Meteorology*, COAPS Report 03-01, Florida State University, pp 38) which identified three important issues with the planned NOAA air-sea observation system: 1) the need for a data quality assurance program to firmly establish that the observations meet the accuracy requirements, 2) the need for observations at high time resolution (about 1 minute), and 3) the need to more efficiently utilize research vessels, including realizing their potential for the highest quality data and their potential to provide more direct and comprehensive observations. For seasonal time scales, the net air-sea flux (sum of 5 flux components) must be constrained within 10 Wm^{-2}. Buoys and VOS systems are required to operate virtually unattended for months, so considerations of practical issues (e.g., power availability, instrument ruggedness, or safe access) are balanced against inherent sensor accuracy and optimal sensor placement. As discussed above, an important function of the in situ measurements is to provide validation data to improve NWP and satellite flux fields. Here, high time resolution and more direct observations are invaluable for interpreting surface flux measurements and diagnosing the source of disagreements; such information can be provided by suitably equipped research vessels (R/V). Thus, the accuracy of buoy and VOS observations must be improved and supplemented with high-quality, high time resolution measurements from the US R/V fleet (which is presently underutilized). The necessity for both high time resolution and high accuracy places extreme demands on measurements because some sources of error (such as the effect of ship flow distortion on wind speed) tend to average out over a large sample. To accomplish this task will require a careful intercomparison program to provide traceability of buoy, VOS, and RV accuracy to a set of standards.

This project directly addresses the need for accurate measures of air-sea exchange (Sections 5.2 to 5.4, *Program Plan for Building a Sustained Ocean Observing System for Climate*). The project is a joint effort by ETL and Dr. Robert Weller of the Woods Hole Oceanographic Institution (WHOI). NOAA COP funds the ETL component and Dr. Weller is seeking NSF funds for the WHOI component. The ETL Air-Sea Interaction Group website can be found at:

http://www.etl.noaa.gov/et6/air-sea/. ETL also cooperates with Dr. Andy Jessup (APL University of Washington) on radiative sea surface temperature measurements, Dr. Frank Bradley (CSIRO, Canberra Australia) on precipitation, Drs. M. Cronin and N. Bond (PMEL) on buoy-ship intercomparisons and climate variability analysis, and Dr. Mike Reynolds (DOE BNL) on radiative fluxes. A new website is under construction for this project (High Resolution Climate Observations). The website is planned to contain a handbook on best practices for flux measurements plus a database of high-resolution flux data. This work will be closely monitored by the new WCRP Working Group on Surface Fluxes (WGSF), which is chaired by C. Fairall. This will give the project high visibility in the CLIVAR, GEWEX, and SOLAS programs. This project will be managed in cooperation with JCOMM (and other) panels as per instructions of Mike Johnson.

FY2004 PROGRESS

For the *Ronald Brown* C-band and wind profiler radar project, hardware upgrades and routine maintenance was performed on the wind profiler prior to the NOAA New England Air Quality Study (NEAQS) conducted off New Hampshire and Maine in July and August 2004. The wind profiler performed well during the cruises and was constantly monitored to evaluate boundary layer wind speed and direction. The C-band radar was also used on this project. While the ship was in Portsmouth, NH, Engineer David Lefcourt of SIGMET, Inc., spent two days upgrading the C-band radar software and improving the functionality of the new LINUX computers that were purchased last year. The software licenses and maintenance were also continued with SIGMET. The C-band radar and wind profiler are also operated during the TAO tender cruise in fall 2004.

ETL completed two research cruises as planned: the annual TAO tender cruise to 95° and 110°W longitude in the equatorial Pacific on board the R/V *Ronald H. Brown* and the joint ETL/WHOI cruise to the climate reference buoy (25°S, 80°W) on board the R/V *Roger Revelle*. Three significant research accomplishments are highlighted here. The joint ETL/WHOI cruise in the fall 2003 signified the first time that air-sea fluxes, cloud remote sensing, and aerosol properties were all measured simultaneously from a ship in the subtropical stratus cloud region. These unique observations showed strong correlations between cloud properties, aerosols, and the air-sea flux forcing of the ocean energy budget. A paper on this has already been accepted for publication (Kollias et al. 2004). A second major accomplishment is the application of parameterizations developed from the ETL TAO tender ship-based observations to an analysis of data from the enhanced monitoring system on the TAO buoys on 95°W (joint with Meghan Cronin of PMEL and Bob Weller of WHOI). This has allowed us to compare the buoy-observed annual cycle of the effects of clouds on the surface energy budget with estimates from satellites, NCEP and ECMWF reanalysis products. This analysis has identified several regions/seasons where the operational products have significant errors and shown that the reason for the errors is incorrect model cloud type (e.g., the model has tropical convective clouds where it should have stratocumulus clouds). A publication on this has also been submitted (Cronin et al., 2004). The third accomplishment involves ongoing work on improving the NOAA/COARE flux algorithm through direct measurements of air-sea gas transfer. The use of trace gases allows us to dig into internal details of the algorithm associated with the partition of oceanic versus atmospheric transport processes. We completed a comparison of the algorithm with data from the NOAA Carbon Cycle program's GASEX-01 field program (see Hare et al., 2004). Also, in 2003 we hosted a piggyback project from the University of Hawaii on the *Ronald Brown*'s fall TAO tender cruise. This resulted in the first ever direct measurements of DMS flux from a ship. This technological breakthrough adds a second (along with CO_2) biologically coupled gas transfer process to our capabilities (see Huebert et al. 2004).

3.15a. Global Repeat Hydrographic/Co_2/Tracer Surveys In Support Of CLIVAR And Global Carbon Cycle Objectives: Carbon Inventories And Fluxes

by Project Managers: Richard A. Feely and Rik Wanninkhof
Co-Principal Investigators: Christopher Sabine, Gregory Johnson, Molly Baringer, John Bullister, Calvin W. Mordy, Jia-Zhong Zhang

PROJECT SUMMARY

General Overview:

The Repeat Hydrography CO_2/tracer Program is a systematic and global re-occupation of select hydrographic sections to quantify changes in storage and transport of heat, fresh water, carbon dioxide (CO_2), chlorofluorocarbon tracers and related parameters. It builds upon earlier programs (e.g., World Ocean Circulation Experiment (WOCE)/Joint Global Ocean Flux Survey (JGOFS) during the 1990s) that have provided full depth data sets against which to measure future changes, and have shown where atmospheric constituents are getting into the oceans. The Repeat Hydrography CO_2/tracer Program (Fig. 1; Table 1) will reveal much about internal pathways and changing patterns that will impact the carbon sinks on decadal time scales. It is designed to assess changes in the ocean's biogeochemical cycle in response to natural and/or man-induced activity. Global warming-induced changes in the ocean's transport of heat and freshwater, which could affect the circulation by decreasing or shutting down the thermohaline overturning, can be followed through long-term measurements. Below the 2000 m depth of the Argo array, Repeat Hydrography is the only global measurements program capable of observing these long-term trends in the ocean. The program will also provide data for the Argo sensor calibration (e.g., www.argo.ucsd.edu), and support for continuing model development that will lead to improved forecasting skill for oceans and global climate.

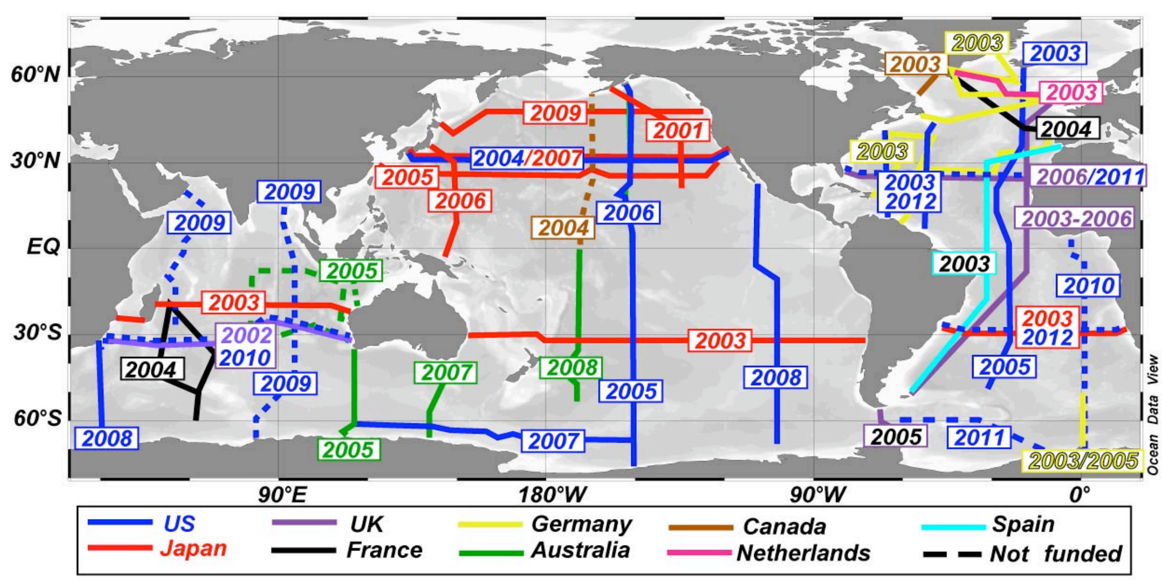


Figure 1. Global map of planned Repeat Hydrography CO_2/tracer Program hydrographic sections with carbon system measurements. Solid lines indicate funded lines. Dashed lines indicate planned lines that are not fully funded at this time. The U.S. A16S and P16S cruises in the South Atlantic and South Pacific, respectively, are designated with solid blue lines for calendar year 2005.

By integrating the scientific needs of the carbon and hydrography/tracer communities, major synergies and cost savings have been achieved. The philosophy is that in addition to efficiency, a coordinated approach will produce scientific advances that exceed those of having individual carbon and hydrographic/tracer programs. These advances will contribute to the following overlapping scientific objectives: 1) data for model calibration and validation; 2) carbon inventory and transport estimates; 3) heat and freshwater storage and flux studies; 4) deep and shallow water mass and ventilation studies; and 5) calibration of autonomous sensors.

Table 1. Sequence of Repeat Hydrography CO_2/tracer cruises in the oceans for the decade starting in June of 2003.

Schedule of US CO_2/CLIVAR Repeat Hydrography Lines (as of 10/04)

Dates	Cruise	Days	Ports	Year	Contact/Chief Scientist
					Overall Coordinator: Jim Swift, SIO
6/19/03-7/10/03	A16N, leg 1	22	Reykjavik-Madeira	1	Bullister, NOAA/PMEL
7/15/03-8/11/03	A16N, leg 2	28	Madeira - Natal, Brazil	1	Bullister, NOAA/PMEL
9/15/03-10/13/03	A20	29	WHOI - Port Of Spain	1	Toole, WHOI
10/16/03-11/07/03	A22	21	Port Of Spain - WHOI	1	Joyce, WHOI
6/13/04-7/23/04	P2, leg 1	41	Yokohama-Honolulu	2	Robbins, SIO
7/26/04-8/26/04	P2, leg 2	32	Honolulu - San Diego	2	Swift, SIO
1/11/05-2/24-05	A16S	45	Punta Arenas-Fortaleza	3	Wanninkhof/Doney; NOAA/AOML/WHOI
1/8/05-2/18/05	P16S	40	Tahiti-Wellington	3	Sloyan/Swift, WHOI/SIO
2006	P16N	57	Tahiti-Alaska	4	Feely/Sabine, NOAA/PMEL
austral summer 07	S4P/P16S	25.5	Wellington-Perth	5	
austral summer 07		25.5	Wellington-Perth	5	
2008	P18	32	Punta Arenas-Easter Island	6	
2008		35	Easter Island- San Diego	6	
2008	I6S	42	Cape Town	6	
2009	I7N	47	Port Louis/Muscat	7	future planning
2009	I8S	38	Perth- Perth	7	future planning
2009	I9N	34	Perth- Calcutta	7	future planning
2010	I5	43	Perth - Durban	8	future planning
2010	A13.5	62	Abidjan-Cape Town	8	future planning
2011	A5	30	Tenerife-Miami	9	future planning
2011	A21/S04A	42	Punta Arenas-Cape Town	9	future planning
2012	A10	29	Rio de Janeiro-Cape Town	10	future planning
2012	A20/A22	29	Woods Hole-Port of Spain-Woods Hole	10	future planning

Years 1-6 are funded.

National Linkages:

The Repeat Hydrography CO_2/tracer Program is being implemented to maintain decadal time-scale sampling of ocean transports and inventories of climatically significant parameters in support of Objective 8 (Ocean Carbon Monitoring Network) of the Program Plan for Building a Sustained Observing Network for Climate. The sequence and timing for the sections (Fig. 1) takes into consideration the program objectives, providing global coverage, and anticipated resources. Also considered is the timing of national and international programs, including the focus of CLIVAR on the Atlantic in the early years of the program; the Ocean Carbon and Climate Change Program (OCCC) that emphasizes constraining the carbon uptake in the Northern Hemisphere oceans, in part, in support of the North American Carbon Program (NACP); and the international Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program. In addition, the proposed sections are selected so that there is roughly a decade between them and the WOCE/JGOFS occupation.

The scientific objectives are important both for the CLIVAR and the OCCC programs, and for operational activities such as Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS). In mid-2001 the US scientific steering committees of CLIVAR (www.clivar.org) and the Carbon Cycle Science Program, (CCSP; www.carboncyclescience.gov) programs proposed the creation of a joint working group to make recommendations on a national program of observations to be integrated with international plans. Several community outreach programs and efforts have been implemented to provide information about the program, such as a web site with interactive forum (http://ushydro.ucsd.edu/index.html), articles in EOS (Sabine and Hood 2002) and the JGOFS newsletter, as well as AGU and Ocean Science meeting forums. The Repeat HydrographyCO_2/tracer Program addresses the need, as discussed by the First International Conference on Global Observations for Climate (St. Raphael, France; October 1999), that one component of a global observing system for the physical climate/CO_2 system should include periodic observations of hydrographic variables, CO_2 system parameters and other tracers throughout the water column (Smith and Koblinsky 2000; Fine et al. 2001). The large-scale observation component of the OCCC has also defined a need for systematic observations of the invasion of anthropogenic carbon in the ocean superimposed on a variable natural background (Doney et al. 2004; Fig. 1).

The CCSP has identified the critical need for the federal government to begin delivering regular reports documenting the present state of the climate system components. Through this program plan NOAA will develop the infrastructure necessary to build, with national and international partners, the ocean component of a global climate observing system and to deliver regular reports on the ocean's contribution to the state of the climate and on the state of the observing system. The goal of this plan is to build and sustain the ocean component of a global climate observing system that will respond to the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments.

Relationship to NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate: (Objective 8: Ocean Carbon Monitoring Network)
The ocean is the memory of the climate system and is second only to the sun in effecting variability in the seasons and long-term climate change. It is estimated that the ocean stores 1000 times more heat than the atmosphere, and 50 times more carbon. Additionally, the key to possible abrupt climate change may lie in deep ocean circulation. Accordingly, the main objective of the repeat hydrography component of the sustained ocean observing system for climate is to document long-term trends in carbon storage and transport in the global oceans. This program will provide a composite global ocean observing system large-scale observations that includes: 1) detailed basin-wide observations of CO_2, hydrography, and tracer measurements; and 2) data delivery and management. This end-to-end ocean system will provide the critical "up-front" information needed for climate research and assessments, as well as long-term, climate quality, global data sets. At the same time, the data management system will provide the necessary data to serve the needs of the other federal agencies in accomplishing their missions.

International Linkages:
Recognizing the need to develop an international framework for carbon research, various working groups of programs like the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Programme (IHDP), the Intergovernmental Oceanographic Commission (IOC), and the Scientific Committee on Oceanic Research (SCOR) have worked together to develop research strategies for global carbon cycle studies. Based on the recommendations coming from these programs, NOAA and NSF have co-sponsored the Repeat Hydrography CO_2/tracers Program, with program direction coming from the Repeat Hydrography Oversight Committee (Richard Feely and Lynne Talley, co-chairs; http://ushydro.ucsd.edu/index.html). Many other nations are also sponsoring similar carbon studies that are comparable in focus and have been designed to be complimentary to our program (http://www.clivar.org/carbon_hydro/index.htm). Consequently, there is an immediate need for global-scale coordination of these carbon observations and research efforts to achieve the goal of a global synthesis. There is also an urgent need to critically assess the overall network of planned observations to ensure that the results, when combined, will meet the requirements of the research community. Because of these issues, the IOC-SCOR Ocean CO_2 Panel (http://www.ioc.unesco.org/iocweb/co2panel/) and the Global Carbon Project (GCP; http://www.globalcarbonproject.org/) have initiated the International Ocean Carbon Coordination Project (IOCCP; http://www.ioc.unesco.org/ioccp/) to: (1) gather information about on-going and planned ocean carbon research and observation activities, (2) identify gaps and duplications in ocean carbon observations, (3) produce recommendations that optimize resources for international ocean carbon research and the potential scientific benefits of a coordinated observation strategy, and (4) promote the integration of ocean carbon research with appropriate atmospheric and terrestrial carbon activities. It is through the workings of the IOCCP and international CLIVAR that international coordination of data management, data synthesis and scientific interpretation of the global repeat sections results will be implemented. In addition, the Repeat Hydrography CO_2/tracer Program is being managed in accordance with the COSP Ten Climate Monitoring Principals.

FY 2004 PROGRESS

A16N Cruise in the North Atlantic
The Repeat Hydrography CO_2/tracers Program started with the FY03 reoccupation of WOCE Section A16N (a meridional section from Iceland to 6°S nominally along 20°W in the eastern Basin of the N. Atlantic) on the NOAA Ship *Ronald H. Brown* (Table 1; Fig. 1). The cruise ran from Iceland southward past the equator and repeated an oceanographic section occupied in 1988, and again in 1993, looking for possible changes in the physics, chemistry and biology of the ocean in this region. All of the major goals of this expedition were met.

NOAA took the lead on measuring core hydrographic parameters (CTD/O_2, salinity, dissolved oxygen, CO_2 and nutrients) for that cruise. Participating scientists from PMEL, AOML and 13 other scientific institutions made a wide variety of atmospheric and oceanic measurements. Atmospheric (CO_2, chlorofluorocarbons, aerosols) and near surface seawater (temperature, salinity, pCO_2, fluorescence, ADCP) measurements were made while underway along the cruise track. Six ALACE profiling floats were deployed along the section, along with 3 newly developed ‘Carbon Explorer’ profiling floats designed to measure particulate inorganic carbon (PIC). Full water column CTD/rosette casts were made at 150 stations, with 5000 discrete seawater samples collected using a specially designed 36-position, 12-liter rosette package. In addition to the CTD, the rosette frame held a lowered ADCP, transmissometer and particulate inorganic carbon sensor.

Seawater samples were analyzed on board ship for salinity, dissolved oxygen, nutrients, Total CO_2 (DIC), Total Alkalinity (TA), pCO_2, pH, chlorofluorocarbons (CFCs), HCFCs, iron and aluminum and alkyl nitrate. Water samples were collected for shore-based analyses of helium, tritium, dissolved organic carbon, particulate organic and inorganic carbon, ^{13}C and ^{14}C. As the samples were analyzed on board, the data were collected and compiled by the data manager, allowing near real-time examination and comparison of the data sets as they were generated. The A16N CTD and bottle set is publicly accessible on line at: http://whpo.ucsd.edu/data/co2clivar/atlantic/a16/a16n_2003/index.htm. The cruise is designated as A16N_2003a with Expocodes: 33RO200306_01 and 33RO200306_02. Final calibration and processing of the cruise data set is nearly finished and we anticipate completing this process by the end of FY-2004.

During FY04 much effort was devoted to data reduction and quality control of the data. In the quality control procedure each data point was assigned a WOCE quality control flag based on intensive checks of the validity of the data. The data reduction of DIC, pCO_2 discrete, TA, pH, inorganic nutrients and oxygen is detailed in a data report that will be published by CDIAC (Peltola et al. 2004) with a synopses provided below. The quality control was performed in a systematic fashion starting with careful checks of each parameter scrutinizing analyzer performance, duplicate values, notebook entries during the cruise, and screening for outliers in profile plots. Then, contextual quality control procedures were followed by looking at internal consistency of inorganic carbon parameters, and utilizing multi-linear regressions between DIC, TA, and pCO_2 with theta, dissolved oxygen, salinity and nutrients. The difference between the calculated and measured value was calculated and if it exceeded three times the standard deviation of the average difference (ranging from 1500 to 2200 data points depending on the carbon parameter), each parameter used in the algorithm was checked closely. If deemed appropriate a flag indicating a questionable point (QC=3) was added.

What follows are the details on quality control for each parameter checked by our group and the group of Dr. Frank Millero of the U. of Miami, RSMAS, who was funded by NSF to perform TA and pH measurements.

DIC: For the cruise we relied on liquid Certified Reference Materials (CRMs) for calibration of our two coulometers. Precision of analyses was determined by taking duplicate samples at three depths (surface, 1000 m and bottom) at nearly all the casts. The duplicate analyses were performed at different times during the runs, with different coulometer solutions, and between the two instruments. No systematic biases were discerned and the average difference of the samples was 1.0 μmol kg^{-1} for surface values; 1.2-μmol kg^{-1} for duplicate samples at 1000 m and 1.4-μmol kg^{-1} for duplicate samples near the bottom. Figure 2 shows a graph of the difference of all duplicates taken on A16N_2003a. This precision meets our stated goals to quantitatively determine changes natural and anthropogenic over decadal timescales that will be on the order of 10-μmol kg^{-1} in surface water. DIC is the primary carbon parameter needed to determine the anthropogenic uptake of CO_2. Based on the high quality work of the analysts and successful performance of instruments we will attain our goals. We are in the process of quantifying changes compared to the NOAA NAtl-93 cruise. Deep-water value comparisons that are an indication of biases between the cruises are shown in Figure 3. No systematic biases are apparent.

$pCO_2(20)$ discrete: Measurement of discrete pCO_2 at a constant temperature of 20°C is a unique skill of personnel at the NOAA laboratories. The measurement offers the ability to overdetermine the inorganic carbon system thereby making it possible to independently verify the integrity of carbon system parameters. On the NOAA led cruises we measure pH as well thereby making it possible to assess biases in carbonate dissociation constants. This "redundancy" of measurements to cross check quality of data is of critical importance to insure the integrity for climate quality data. pCO_2(discrete) is also very sensitive to changes in inorganic carbon and alkalinity in the ocean making it a good indicator to change. The measurement is challenging requiring an equilibration between water and an isolated headspace. In particular issues with water vapor interference and corrections to perturbation have affected the accuracy that is determined through comparison with CO_2 in air gas standards. For the A16N cruise we changed data reduction routines and how we deal with water vapor correction. This has increased the precision of our measurements that is estimated at 2 μatm or 0.3 % (Fig. 4) but there appears a bias in the deep-water pCO_2 values compared to data in 1993 and 1998. We think it is unlikely that the differences observed are real but to date have not been able to attribute the bias to a particular dataset (Fig. 5).

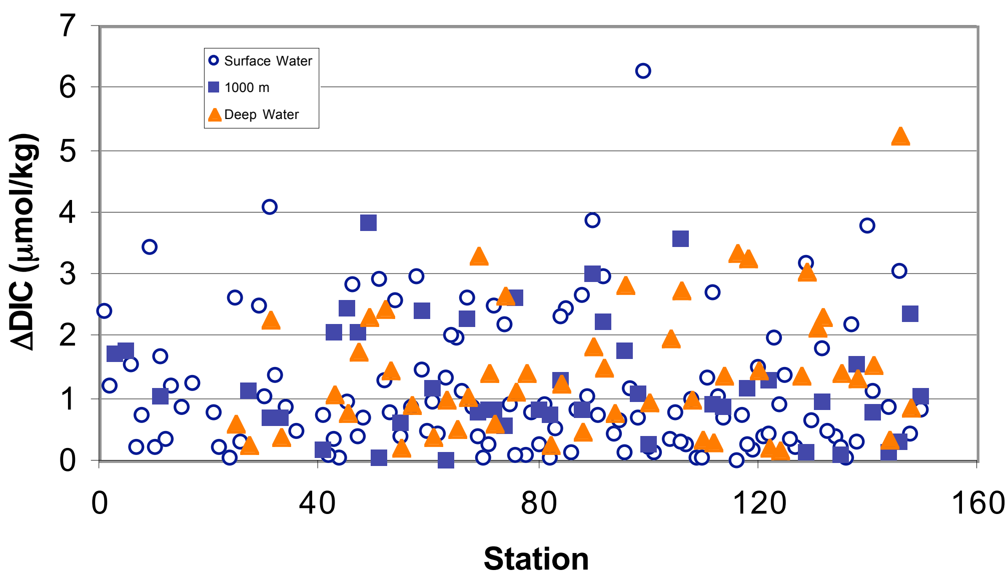


Figure 2. Duplicate DIC values versus station. Open circles are duplicates at the surface; solid squares are duplicates at 1000-m; and triangles are duplicates from near bottom. No systematic differences with depth were observed.

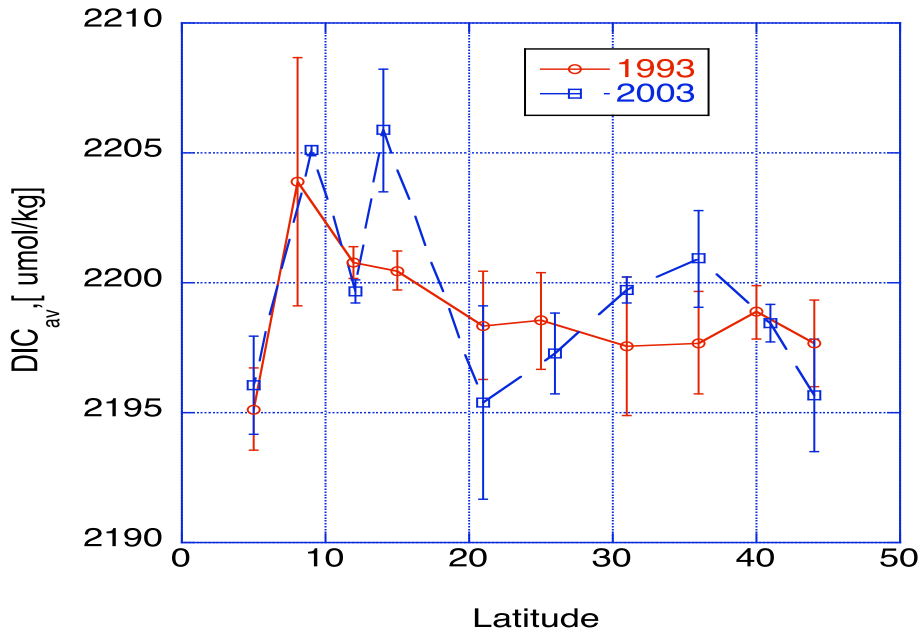


Figure 3. Comparison of deep-water values for DIC between 1993 (red line with open circles) and 2003 (blue line with open squares). The average of two to five bottom water samples at roughly five-degree spacing were compared. No systematic offset is observed with agreement better than 2 μmol kg^{-1}.

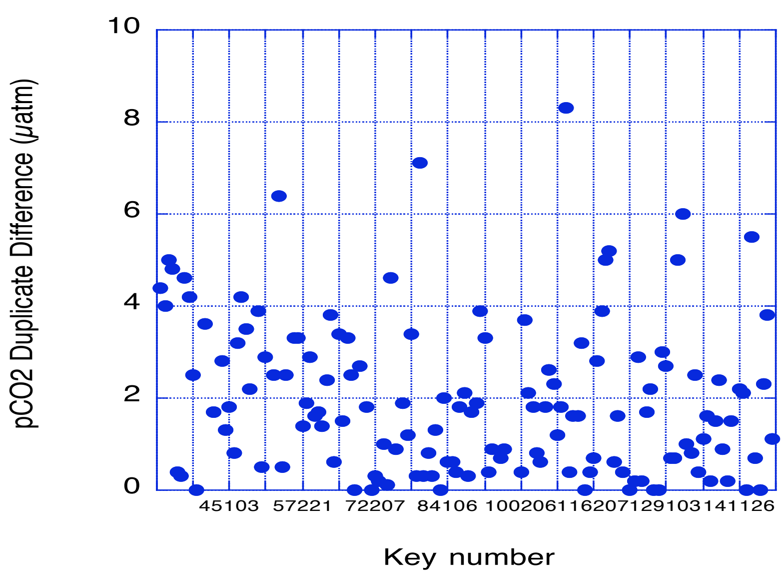


Figure 4. Differences of duplicate pCO_2 samples taken during the A16N-2003a cruise.

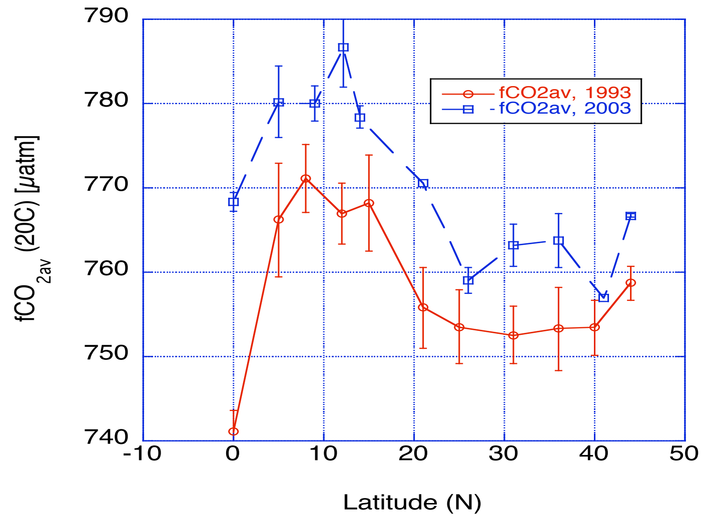


Figure 5. Comparison of deep-water values for discrete pCO_2(20) between 1993 (red line with open circles) and 2003 (blue line with open squares). The average of two to five bottom water samples at roughly five-degree spacing were compared. A systematic offset of about 10 μatm is apparent.

TA and pH: These samples were analyzed by the group of Prof. Millero funded through NSF with details presented in Peltola et al. (2004). Joint quality control procedures of all carbon parameters were undertaken which benefited all parameters. Comparisons with values in 1993 are shown in Figure 6. A comparison of internal consistency of measured TA values and those calculated from DIC and pCO_2(20) are shown in Figure 7. The figure suggests that the TA, pCO_2(20) and DIC values are internally consistent.

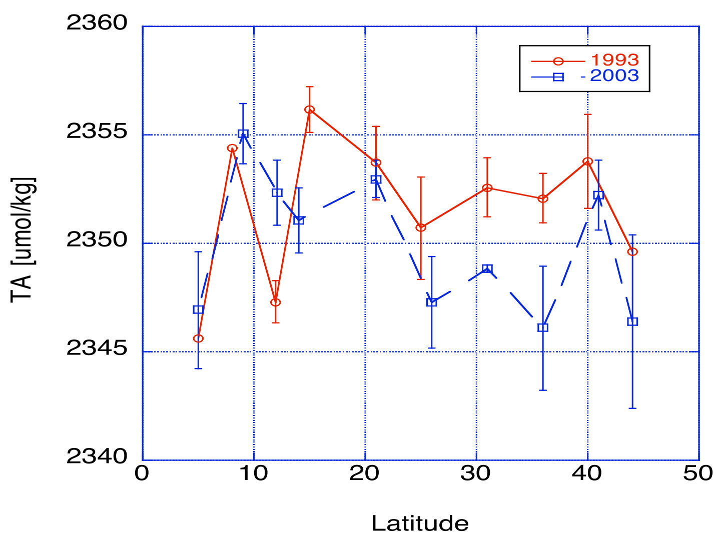


Figure 6. Comparison of deep-water values for TA between 1993 (red line with open circles) and (blue line with open squares). The average of two to five bottom water samples at roughly five-degree spacing were compared. There appears a small systematic offset of about 2-μmol kg^{-1} for several of the stations.

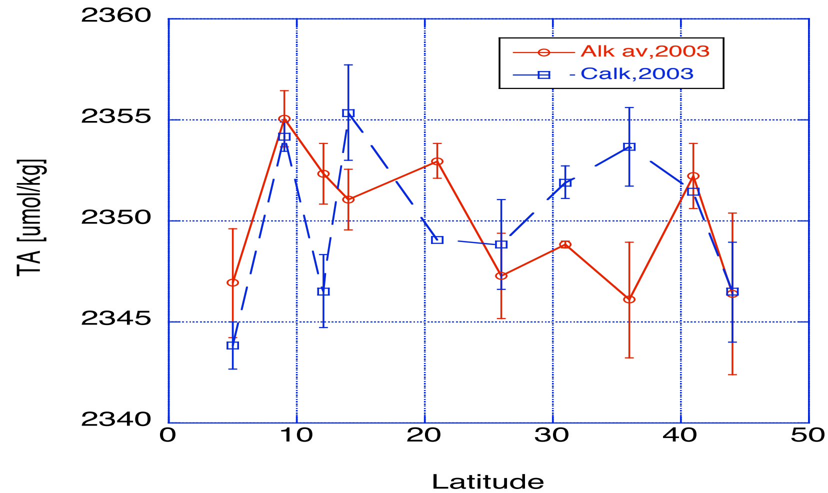


Figure 7. Comparison of deep-water values for measured TA for 2003 (red line with open circles) and calculated TA from $pCO_2(20)$ and DIC (blue line with open squares). Two to five bottom water samples at roughly five-degree spacing were compared. There is no clear offset between values.

Dissolved Oxygen: A total of ~5000 samples were taken on A16N, which included samples from each Niskin bottle. Precision based on 20 replicates taken at the first station is 0.1%. On the whole, dissolved oxygen analyses were problematic during the cruise. Lack of attention to detail compromised the quality. In particular the oxygen equipment had been used on cruises preceding A16N and problems with the instrument, in particular the pipettes to dispense standard, and sample bottle breakage and replacement was not relayed to the analysts on A16N. Sample bottle volumes must be known as the titration is performed on the whole sample right in the bottle. Following the cruise, all bottle volumes were re-determined and pipettes were recalibrated after which the data reduction was performed from scratch. The data were subsequently quality controlled by the cruise Chief Scientist J. Bullister by checking profiles and comparing with oxygen data from the Oceanus 202 cruise and the NOAA/OACES NATl -93 cruise that occupied the same transect in 1988 and 1993, respectively. Following post-cruise processing, agreement between deep-water values on the A16N and Oceanus 202 cruises is ± 2-μmol kg^{-1}.

Nutrients: Nutrient samples were taken from all Niskin bottles. Samples were analyzed for nitrate, nitrite, phosphate and silicate on an auto-analyzer. Data are of excellent quality. Precision based on duplicate samples taken from the bottom Niskin bottle is 0.08-μmol kg^{-1} (≈ 0.2 %) for nitrate, 0.01-μmol kg^{-1} (≈ 0.3 %) for phosphate, and 0.1-μmol kg^{-1} (≈ 0.1 %) for silicate.

A detailed analysis and interpretation of these cruise data should greatly improve our understanding of key ocean processes in this region and how they may be changing on decadal timescales. The results will be presented at a special session of the 2004 Fall AGU meeting and significant findings will be published in the scientific literature. Some key initial findings from the A16N cruise are that between the 2003 section and earlier occupations, significant changes in water mass properties, including temperature, salinity and dissolved oxygen, were observed in subpolar mode waters and Labrador Sea water. The changes in apparent oxygen utilization (AOU) observed may be due to changes in the strength of ventilation processes in the region during the decade prior to the 2003 occupation compared to the years prior to the earlier samplings, as well as to possible changes in biological production, and organic matter export and remineralization rates. Regions in the water column with large increases in apparent oxygen utilization (AOU) tended to have relatively large increases in pCFC derived apparent ages, indicating that the AOU changes may be driven in part by a slowdown in the strength of the ventilation processes. Simple numerical model simulations are being used to estimate the contribution of steady-state mixing processes to the temporal trends in pCFC derived apparent age fields observed in this region. NOAA was responsible for the DIC measurements on the FY04 Repeat Hydrography CO_2/tracer Program cruises. During FY04 post-cruise instrument calibrations for A16N were performed, bottle salinity, nutrient and carbon data were finalized, as were CTD temperature and salinity data. Corrections of bottle oxygen data have just been completed, and final CTD oxygen calibrations are just getting started, which will allow a final check of the bottle oxygen data. The CFC group worked on final data quality control for the CFC data collected on the A16N cruise, and J. Bullister coordinated final data quality evaluation of the other parameters measured during the cruise. Initial analysis of the first results from the Repeat Hydrography Program has begun. Some of these results were presented at the First International CLIVAR Science Conference and also will be presented at a special session of the Fall 2004 AGU meeting.

A20/A22 Cruises in the North Atlantic:
The A20/A22 cruises commenced in mid-September 2003 aboard the *R/V Knorr* from Woods Hole, MA and were completed in November. The first leg (A20) was along 52°W and ended in Trinidad; the second leg (A22) was along 66°W and ended back in Woods Hole (Table 1). Scientists from NOAA were responsible for DIC measurements. During the two cruises 150 stations were occupied and >3200water samples were collected for analysis of DIC. The quality of the measurements was considered excellent based on results of the analyses of the CRMs (Figure 8). In addition to DIC, samples also were analyzed on board ship for salinity, dissolved oxygen, nutrients, TA, and CFCs. Water samples were collected for shore-based analyses of helium, tritium, dissolved organic carbon, ^{13}C and ^{14}C. As the samples were analyzed on board, the data were collected and compiled by the data manager, allowing near real-time examination and comparison of the data sets as they are generated.

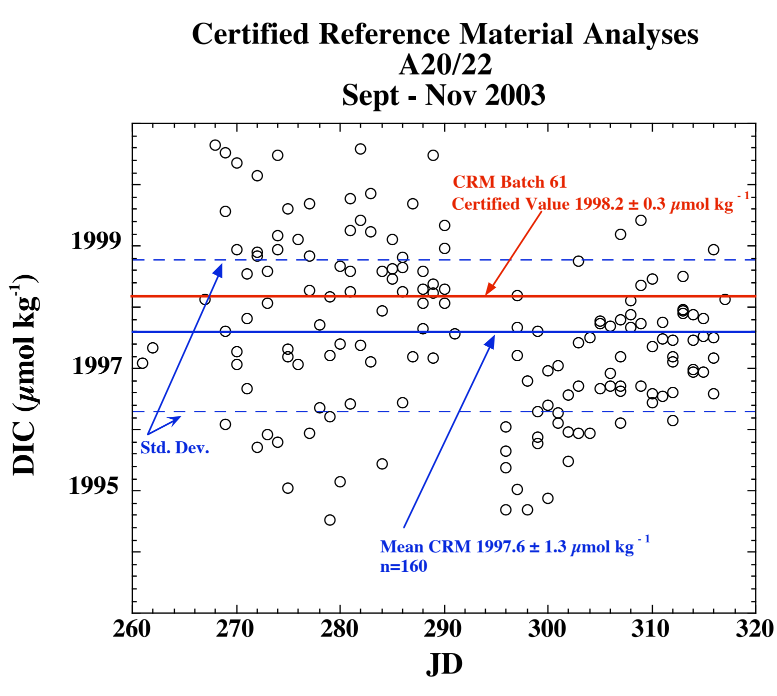


Figure 8. Results of CRM analyses during A20/22 in the Atlantic between Sept – Nov 2003.

The DIC results from the A20 cruise (Figure 9a) along 52°W can be compared to previous cruise results from the 1997 occupation (Figure 9b). The difference plot (Figure 9c) indicates significant increases of DIC in the shallow waters masses over the depth range of 100-600 m between the last occupation of these stations during the WOCE era (1997) and the 2003 occupation. For example, along the 200-600 m depth range, DIC increases on the order of 2-20 μmol kg^{-1} were observed over the six year period between the two cruises (Figure 9c). In contrast, the DIC at depths >1000 m showed very little change (Figure 9c). These increases of DIC in the Subtropical Mode waters (STMW) may be the result of decadal changes in the local circulation, invasion of anthropogenic CO_2 into the interior North Atlantic, and/or changes in new production and remineralization of organic matter along the flow path. As we continue to process the physical and biogeochemical data from these cruises, we should be able to determine the large-scale changes in the carbon content of the Atlantic Ocean.

The DIC results from the A22 cruise (Fig. 10a) along 66°W can be compared to previous cruise results from the 1997 occupation (Fig. 10b). The difference plot (Fig. 10c) indicates similar increases of DIC in the Subtropical Mode (STMW) further to the west. The DIC increases are highest between 20 and 25°N in the western North Atlantic.

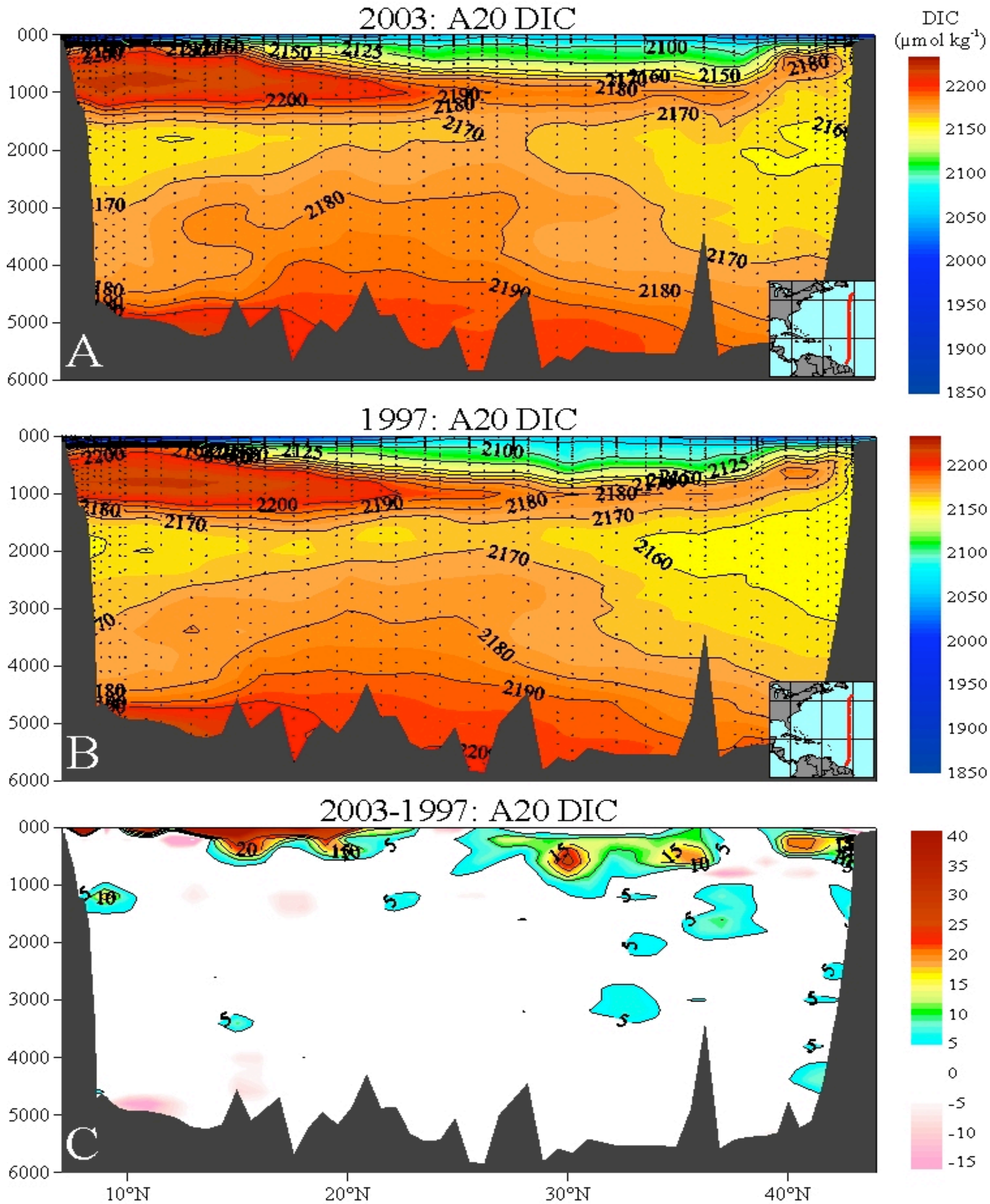


Figure 9. Distribution of DIC (μmol kg^{-1}) along 52°W in the western North Atlantic during the 2003 reoccupation (9a), the 1997 occupation (9b), and the difference 2003 – 1997 (9c).

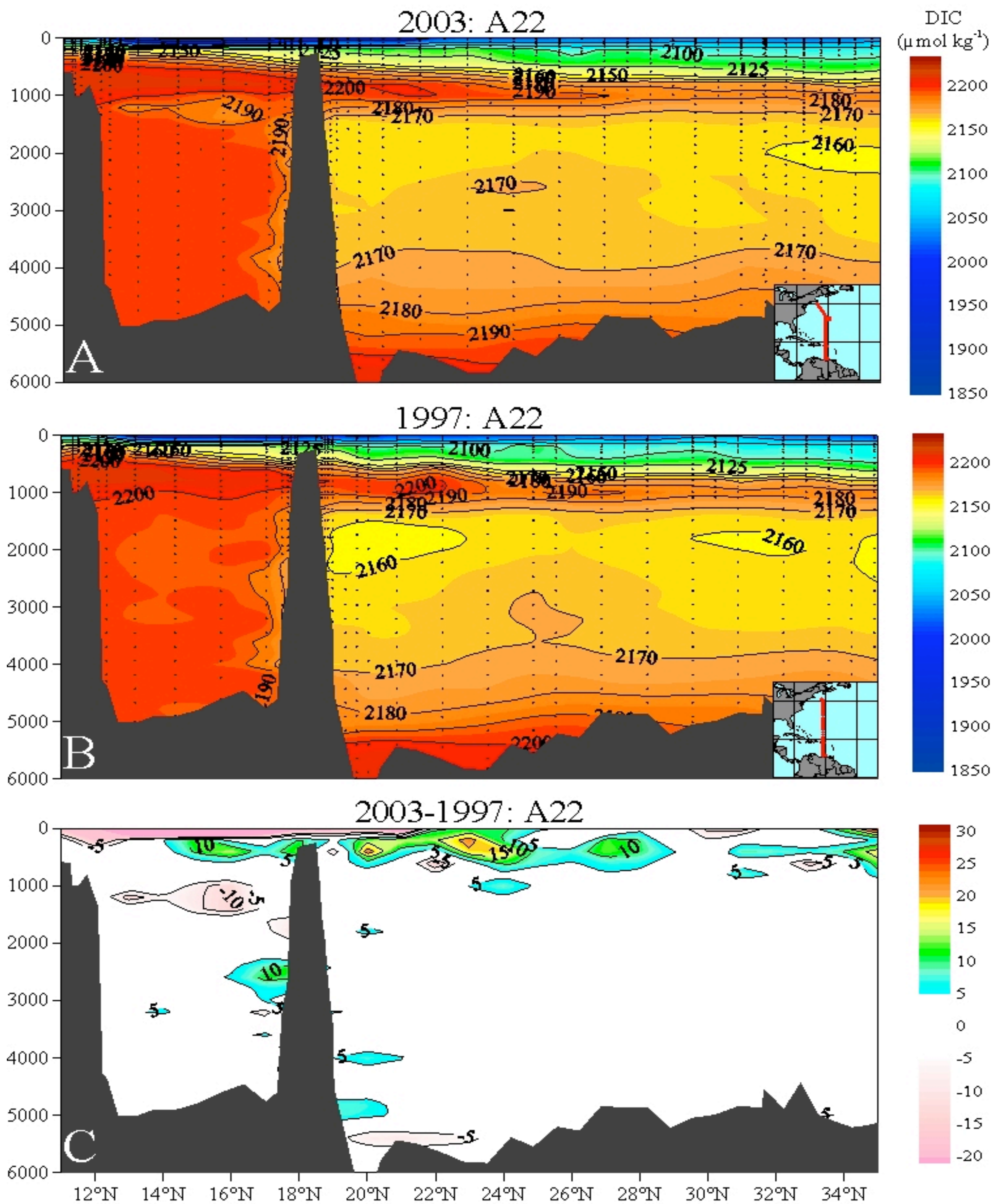


Figure 10. Distribution of DIC (μmol kg^{-1}) along 66°W in the western North Atlantic during the 2003 reoccupation (10a), the 1997 occupation (10b), and the difference 2003 – 1997 (10c).

P2 Cruise in the North Pacific:
The P2 cruise commenced in June aboard the *R/V Melville* from Yokohama, Japan with Leg 1 ending in Honolulu. Tightly spaced stations were taken angling southeast across the Kuroshio Current, and then an easterly transect was begun along 30°N/135°W. Two typhoons caused delays early in the leg, and as a consequence, station spacing was increased slightly. Leg 2 started from Honolulu and continued stations along 30°N ending in San Diego. Seawater samples were analyzed on board ship for salinity, dissolved oxygen, nutrients, DIC, TA, and CFCs. Water samples were collected for shore-based analyses of helium, tritium, dissolved organic carbon, ^{13}C and ^{14}C. During the cruise 190 stations were occupied and ≈ 6,000 water samples were collected for analysis of all these parameters. As with the previous Repeat Hydrography cruises, the real time data analyzed aboard were collected and compiled by the data manager and will be submitted to the CLIVAR and Carbon Hydrographic Data Office (CCHDO; http://cchdo.ucsd.edu/) and CDIAC. Preliminary evaluation of the shipboard data indicates that they are of high quality and should meet or exceed WOCE guidelines.

NOAA was responsible for the DIC measurements on P2. The full water column was analyzed for DIC on even stations, and generally the upper 1200m analyzed on alternate stations. Results of analyses of CRMs indicate that the data quality is excellent (Fig. 11). The accuracy and precision of the analyses is

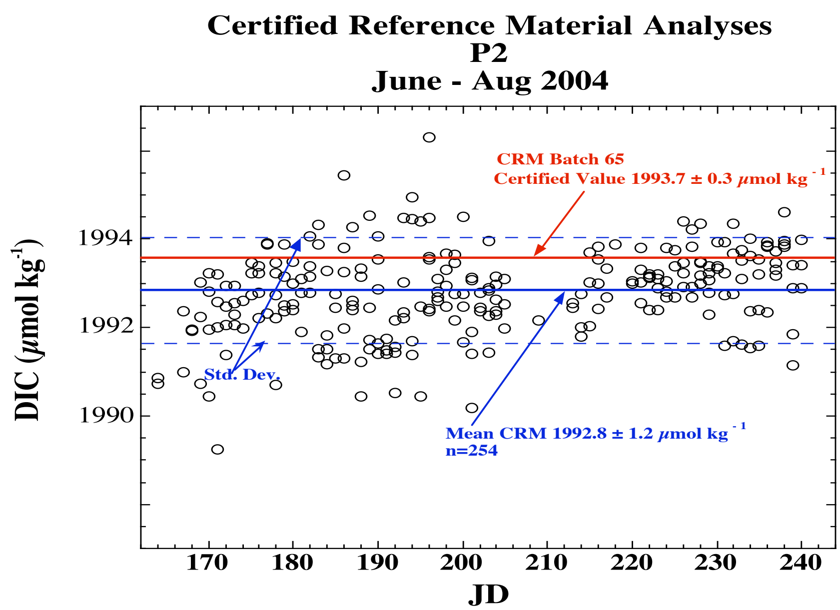


Figure 11. Results of CRM analyses on P2 cruise in the N. Pacific during June – Aug 2004.

Well within the maximum error of ±2 μmol kg^{-1} needed to quantitatively determine changes of natural and anthropogenic CO_2 over decadal timescales. Difference plots for the 2004 Repeat Hydrography – the 1994 WOCE cruises are shown in Figs. 12 and 13 for salinity and temperature, respectively. Significant differences are observed in surface waters and in intermediate depths ranging from 200-1000 m. The differences may be due to changes in the strength of ventilation processes in the region during the decade prior to the 2004 occupation compared to the years prior to the earlier samplings or to possible changes due the presence of eddies. Figs. 14 and 15 show the corresponding distributions and difference plots for AOU and DIC. The AOU maxima and minima correspond very closely with the DIC maxima and minima, suggesting that similar physical and/or biogeochemical processes are controlling the distributions of both parameters. While these results indicate that the quality of the overall data sets are quite good, they also suggest that local mesoscale processes are important and must be determined before the long-term trends can be isolated from the data sets.

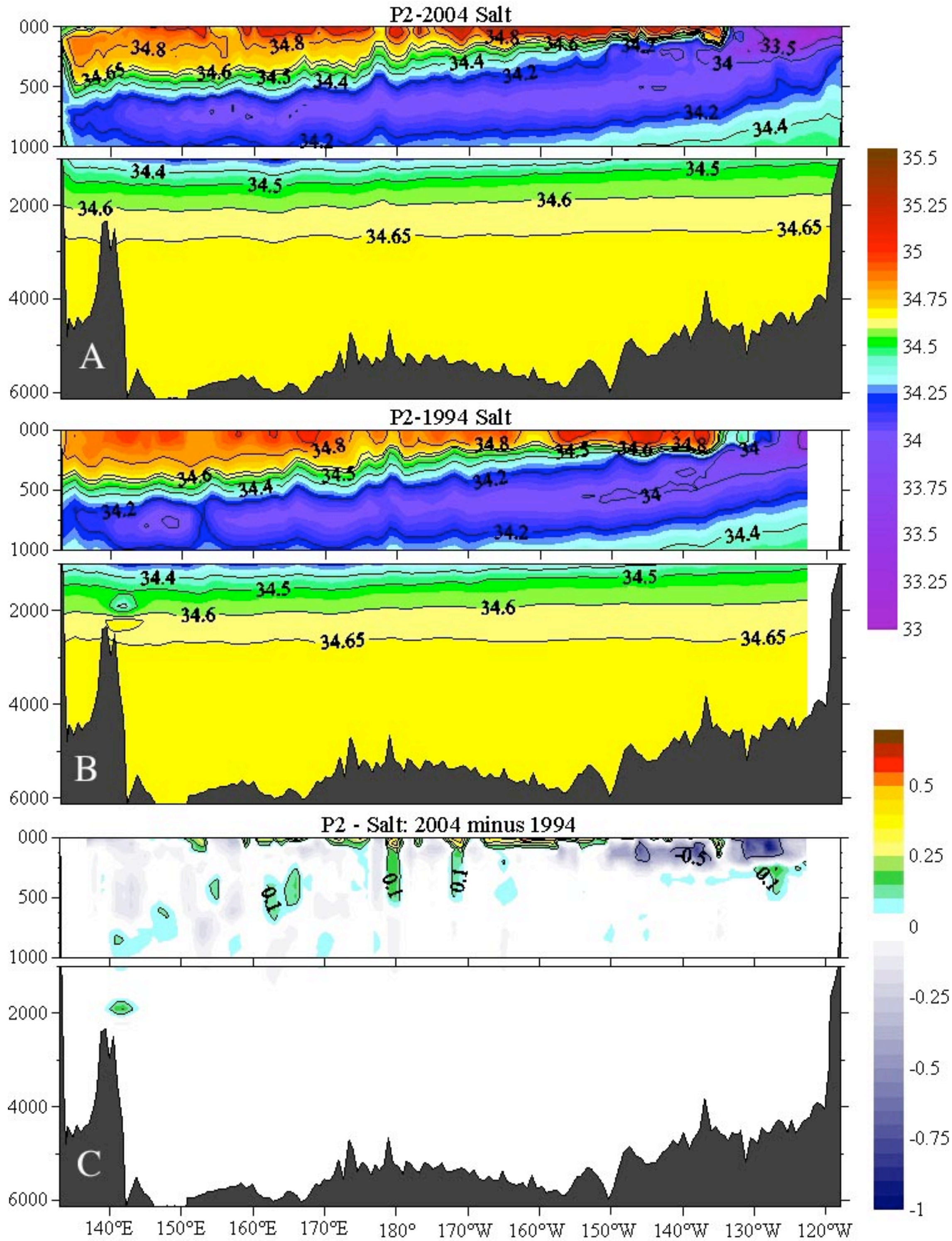


Figure 12. The difference plots for both salinity and temperature results from the P2 cruise.

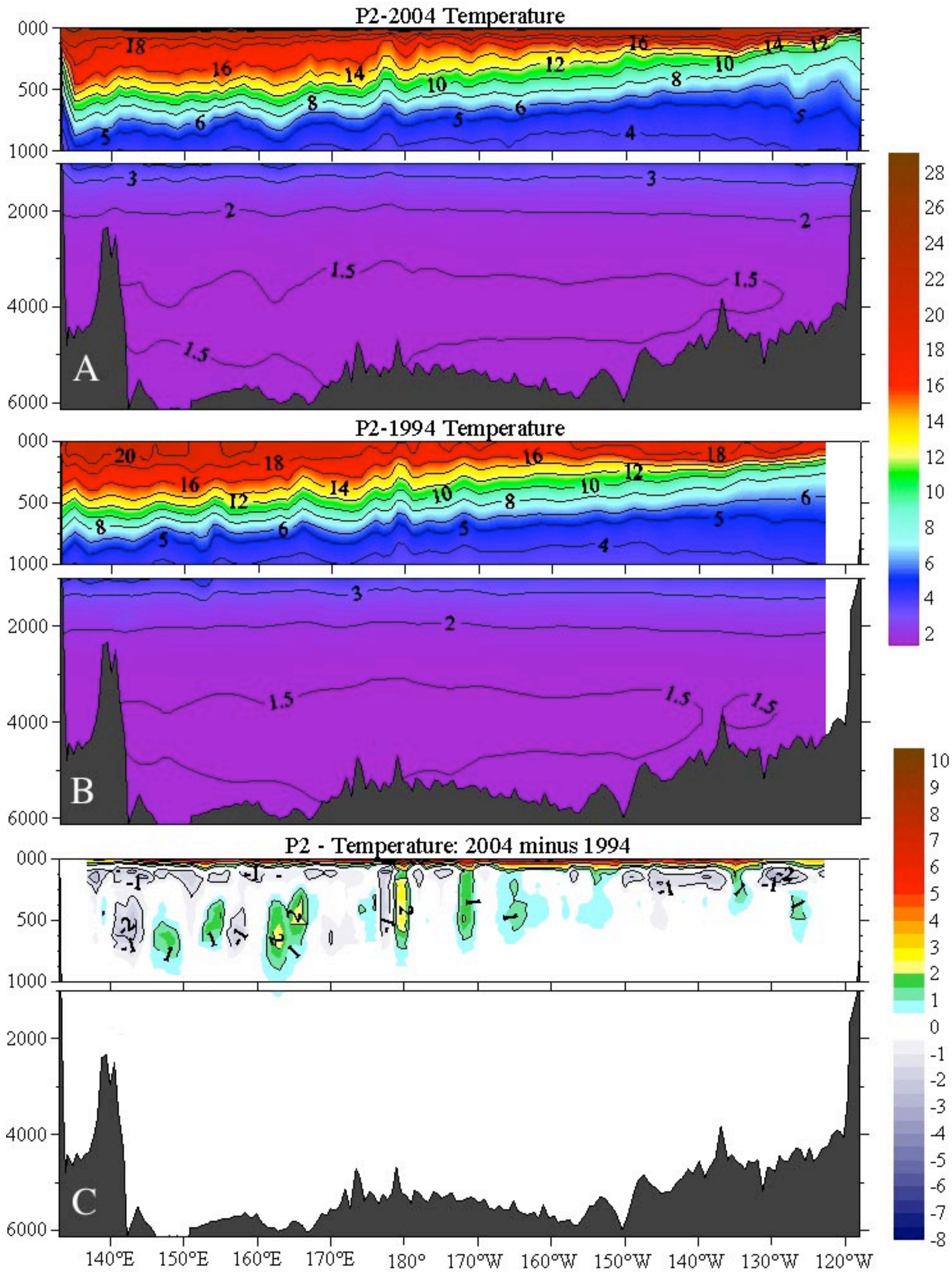


Figure 13. Distribution of temperature (°C) along 30°N in the North Pacific during the 2004 reoccupation (13a), the 1994 occupation (13b), and the difference 2004 – 1994 (13c).

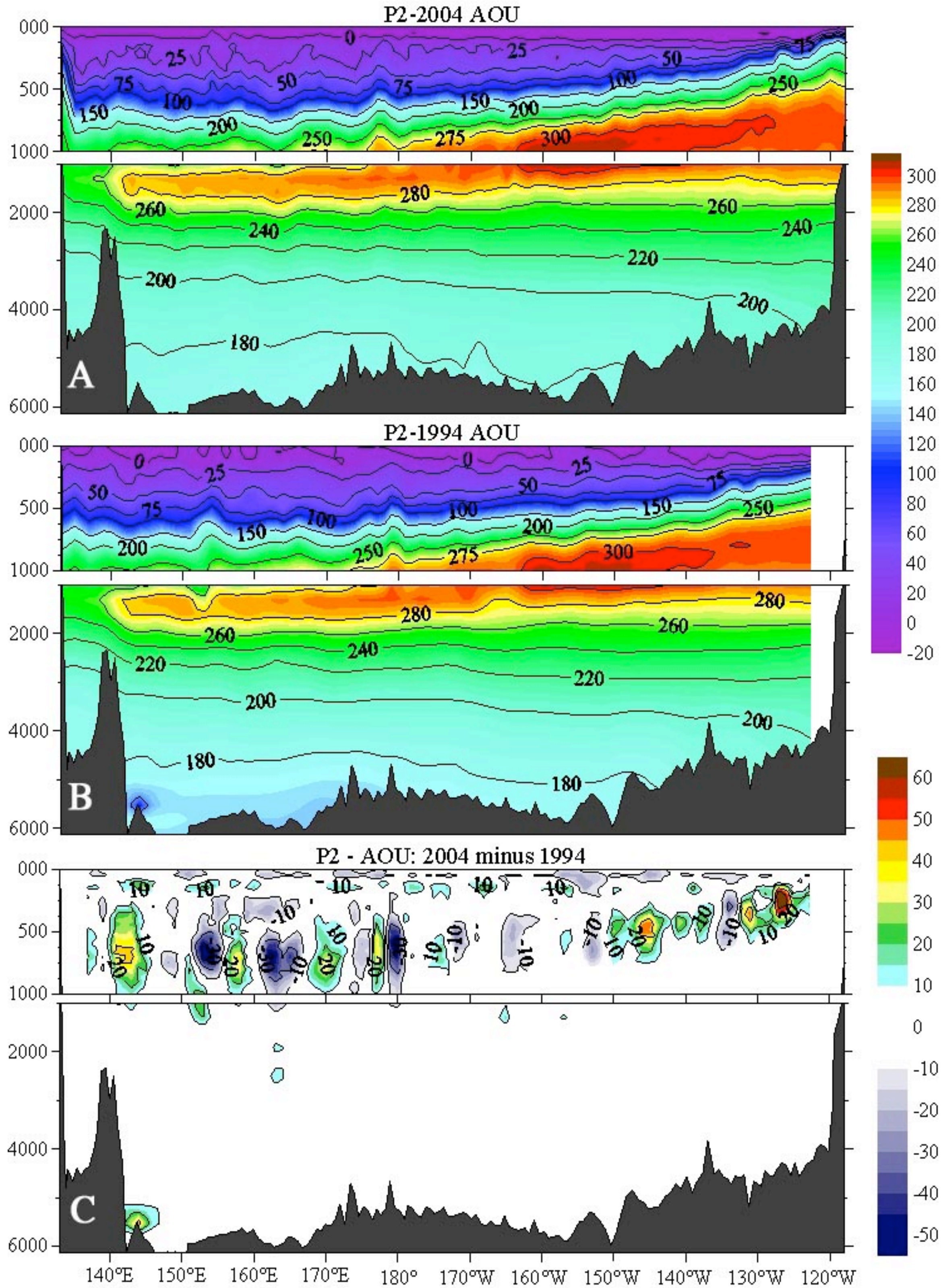


Figure 14. Distribution of AOU (μmol kg^{-1}) along 30°N in the North Pacific during the 2004 reoccupation (14a), the 1994 occupation (14b), and the difference 2004 – 1994 (14c).

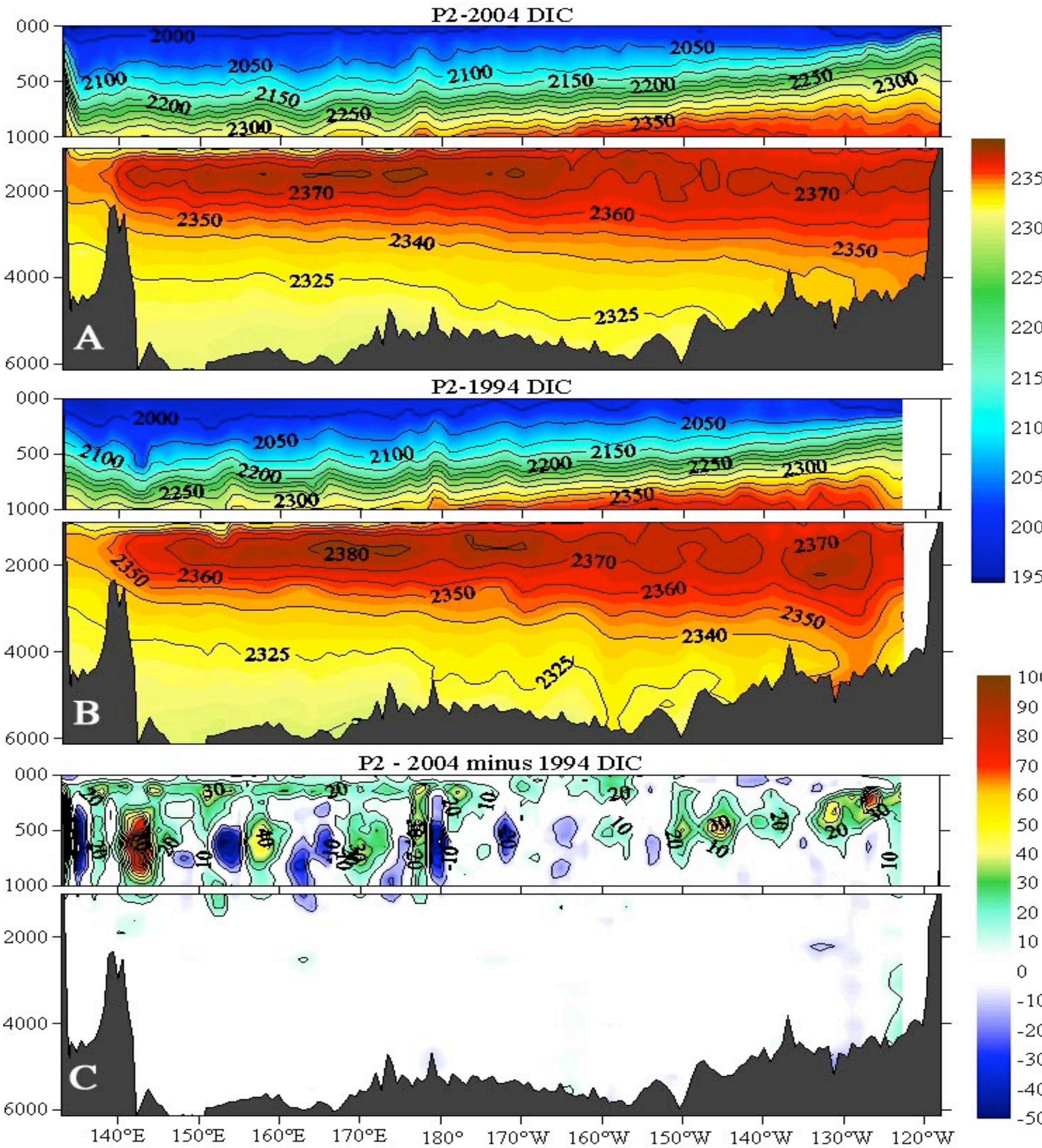


Figure 15. Distribution of DIC (μmol kg^{-1}) along 30°N in the North Pacific during the 2004 reoccupation (15a), the 1994 occupation (15b), and the difference 2004 – 1994 (15c).

A16S Cruise in the South Atlantic:
In FY04, preparations for the FY05 repeat of A16S (a meridional section from 60°S to 4°S nominally along 25°W in the western basin of the South Atlantic) on the NOAA Ship *Ronald H. Brown* have begun. Scientific supplies (salinity bottles, a laptop computer, cable terminations, a CTD oxygen sensor, a bottle frame cover, a nutrient detector, o-rings, etc.) have been purchased. In addition CTDs, frames, pylons, water sampling bottles, nutrient detectors and the like have been assembled, checked, maintained, and prepared for shipping. Nutrient analysis software has been upgraded.

P16S Cruise in the South Pacific:
Preparations for the reoccupation of P16S (a meridional section from 20°S to 67°S along 150°W) have begun for the January-February 2005 period. NOAA is responsible for DIC and underway pCO_2 measurements on P16S, and will send two analysts to participate on the cruise.

PMEL Tracer Efforts in FY2004:
The PMEL CFC Tracer group did not have fieldwork scheduled in FY 2004 as part of Global Repeat Hydrography CO_2/tracer Program. To help maintain support for CFC personnel (F. Menzia -JISAO and D. Wisegarver) during this period, F. Menzia participated on Repeat Hydrography Program sections A22 and P2 as a CFC analyst, supported by the UM/RSMAS group. D. Wisegarver participated on section P2 as a DIC analyst, supported by the PMEL Carbon group. Menzia and Wisegarver also assisted with the development of instruments with the Carbon and Hydrographic groups at PMEL during this period.

During FY 2004, the PMEL CFC group blended and calibrated gas-phase CFC standards for CFC-11, CFC-12, CFC-113 and carbon tetrachloride in high-pressure gas cylinders. These cylinders were initially analyzed at PMEL for uniformity and were monitored for possible concentration drift. These standards have been distributed to the US groups participating in the Repeat Hydrography Program Addition cylinders were prepared for distribution to international groups participating in the Repeat Hydrography Program. We anticipate that this set of cylinders will provide a reliable CFC standard reference material for the upcoming decade.

Data from the Repeat Hydrography Program are located at the CLIVAR and Carbon Hydrographic Data Office (http://cchdo.ucsd.edu/) as well as at CDIAC, where they are freely and publicly accessible. These data are being used widely in scientific studies on variability in ocean ventilation (including impacts on ocean heat, salt, oxygen, nutrients and carbon). Data from A16N were first presented in posters given at the 1st International CLIVAR Science Conference, June 2004, Baltimore, Maryland. More detailed presentations, including results from additional Repeat Hydrogaphy cruises will be given at the AGU Fall Meeting, December 2004, San Francisco, California as part of the special session entitled "Decadal Variations in Ocean Interior Circulation and Biogeochemistry: First Results From the CLIVAR/CO_2 Repeat Hydrography Program."

3.16a. Surface Drifter Program

by Silvia L. Garzoli and Robert L. Molinari

PROJECT SUMMARY

This program combines the previous AOML drifter component of the ENSO observing system (Molinari and Cook PIs, now "Operations") and the Tropical and sub-tropical Atlantic Surface Drifters Array (Garzoli, PI, now "Atlantic drifters"). Participants in the combined program are Bob Molinari, Silvia L. Garzoli, Steve Cook, Rick Lumpkin, Mayra Pazos, Craig Engler and Jessica Redman.

General overview of the project, including brief scientific rationale:

Operations

The primary objective of the former AOML drifter component of the ENSO Observing System is to provide oceanographic data needed to initialize the operational seasonal-to-interannual (SI) climate forecasts prepared by NCEP. Specifically, AOML manages a global drifting buoy network that provides sea-surface temperature (SST), surface current and air pressure data needed to (a) calibrate SST observations from satellite; (b) initialize SI forecast models; and (c) provide nowcasts of the structure of global surface currents. Global drifter coverage is required as the forecast models now not only simulate Pacific conditions but global conditions to improve prediction skill. Secondary objectives of this project are to use the resulting data to increase our understanding of the dynamics of SI variability, and to perform model validation studies. Thus, this project addresses both operational and scientific goals of NOAA's program for building a sustained ocean observing system for climate.

b. Atlantic Drifters

The main objectives of this program, a joint effort between SIO and the AOML that started in 1997, is to deploy and maintain an array of SVP drifting buoys in the tropical Atlantic, within 20 degrees of latitude of the equator for the purpose of filling up the gaps to accurately observe the basin-wide scale tropical current and SST fields on time scales of the inter-annual variations of tropical Atlantic SST. In FY03, a new component of this program started to partially solve the problem of data scarcity in the subtropical south Atlantic (20°S to 40°S).

Large-scale SST distributions drive the response of the climate in the tropical Atlantic sector, and over land areas as distant as the southern and eastern Unites States. In spite of its importance, no dynamical model has successfully predicted tropical Atlantic SST one-to-several seasons in advance. The current generation of coupled ocean-atmospheric models cannot reproduce, much less predict, the SST in the tropics. A recent comparison of 23 GCM results (Davey et al. 2002) concentrated on simulated fields from the tropical oceans (i.e. SST, zonal wind stress and upper layer depth averaged temperature). In the Atlantic Ocean, discrepancies between the model and observed mean states were dramatic. Specifically, in the equatorial Atlantic, the simulated meridional temperature gradient was wrong, with cold temperatures in the west and warm temperature in the east (Figure 4, Davey et al. 2002[1]). Furthermore, the variability of the sub-tropical Atlantic and its interaction with the tropics is far from being understood. This is primarily due to the paucity of data that for years has been mainly collected in the major commercial lanes. Products of SST are considerably deficient in the center of the south Atlantic basin and between 20°S to 40°S. A recent paper (Kushnir et al. 2003[2]) demonstrated that the variability of the inter-tropical converge zone (ITCZ) is highly sensitive to changes in SST gradients within the broader tropical Atlantic region, particularly in the meridional direction south of the tropics and during the boreal spring. To better understand this variability, it is necessary to improve the SST products in the South Atlantic. The development and future success of such models will depend on understanding the processes driving SST changes and providing products based on observations that models can attempt to simulate.

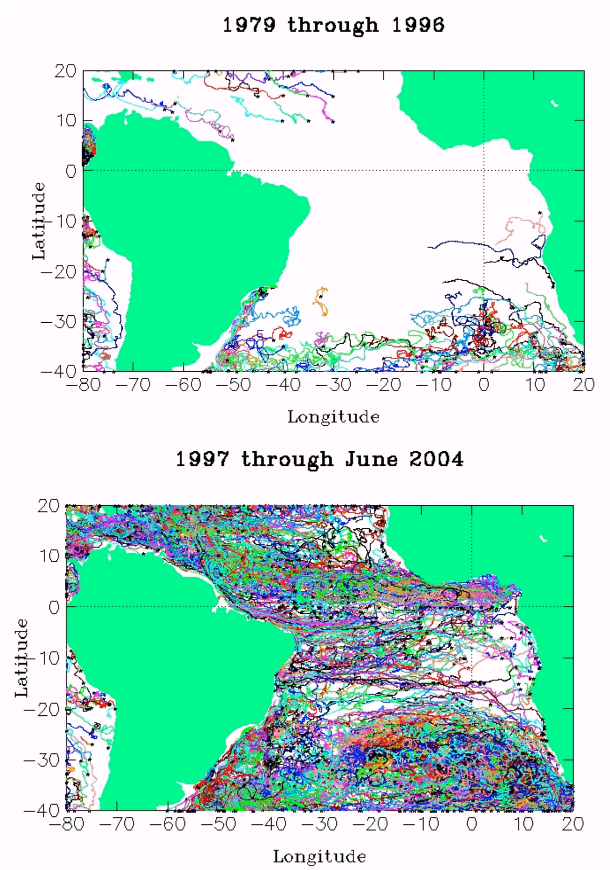


Figure 1: Evolution of the tropical Atlantic surface drifters array. Left: trajectories of drifters deployed in or entering the region from 1979 through 1997 (18 years); Right: trajectories of drifters deployed in or entering the region, funded under the Atlantic drifters (20°N - 40°S) from 1997 through June 2004 (7.5 years).

Statement about how your project addresses NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate:

This project provides critical data for initializing seasonal to interannual forecasts. In addition, this program is a direct component of NOAA's Program Plan for building a *Sustained Observing System for Climate*. The first milestone for in-situ networks in this plan is to "Deploy an array of 1250 drifting buoys for sea surface temperature, pressure and current measurement by 2004".

Statement about how your project is managed in cooperation with the international implementation panels, in particular the JCOMM panels:

The GOOS Center and its integral component, the Global Drifter Program (GDP) is a participating member of JCOMM and JCOMMOPS. Both the GDP and GDP – Data Assembly Center (DAC) are represented annually at the WMO/IOC Data Buoy Cooperation Panel (DBCP) and Joint Tariff Agreement (JTA) meetings. Participation on these international panels provides an important mechanism for integrating and coordinating with other national or regional programs which, in the long run, improves our national climate mission by making more efficient and effective use of available resources.

Responsible institutions for all aspects of project:
The GOOS Center located within the Physical Oceanography Division at AOML manages and operates the Global Drifter Program (GDP). The GDP is closely aligned with the Scripps Institution of Oceanography, SIO, for the procurement of Drifting Buoys. The GDP utilizes the National Weather Service Global Telecommunications System (NWSGTS) gateway for the real-time distribution of data and the National Oceanographic Data Center (NODC) and Marine Environmental Data Services (MEDS) for the archival of delayed mode data. The data are placed on GTS for operational use by Service Argos. AOML, under the direction of Mayra Pazos, quality controls and processes these data to quarter - day intervals and on six-month intervals sends to Marine Environmental Data Service (MEDS)/Canada for international distribution.

Project web site URL and pertinent web sites for your project and associated projects:
The program web site is maintained and updated by Mayra Pazos, DAC manager.
http://www.aoml.noaa.gov/phod/dac/

- Associated projects links
  - http://www.jcommops.org
  - http://www-hrx.ucsd.edu
  - http://www.cmdl.noaa.gov
  - http://www://sahfos.org
  - http://www.aoml.noaa.gov/phod/benchmarks/index.html
  - http://www.aoml.noaa.gov/phod/enso/index.html
  - http://www.aoml.noaa.gov/phod/taos/index.html

Interagency and international partnerships:
Drifters are launched using the AOML/GOOS infrastructure of NOAA interagency and international partners. Specifically, participation on the Data Buoy Cooperation Panel (DBCP) increases deployment opportunities.

Statement that your project is managed in accordance with the Ten Climate Monitoring Principles:
This program is managed in accordance with the Ten Climate Monitoring Principles (Program Plan, Mike Johnson 2003).

FY 2004 PROGRESS

Instrument/platform acquisitions for fiscal year and where equipment was deployed:
Operations: All Drifters for the Global Drifter Center are purchased by SIO. Drifting Buoys are deployed globally, in all four oceans (Pacific, Atlantic, Indian and Southern).
Atlantic drifters: Drifters for the Atlantic program are purchased by AOML. During FY04, a 100 buoys were deployed within the tropical Atlantic (30°N – 20°S), and 41 SVP buoys (9 upgraded with barometers) were deployed in the subtropical south Atlantic (20°S- 40°S).

Number of deployments – compare to the previous year:
The number of operations deployments (except for the Atlantic) increased from 222 in FY03 to 509 in FY04.
The number of deployments in the tropical Atlantic increased from 79 in FY03 to 100 in FY04.
The number of deployments in the subtropical south Atlantic was increased by 41 in FY04.

Percentage data return for fiscal year and 'lifetime' statistics – compare to the previous year:

The following statistics are for the global array, and includes the Atlantic drifters: On average on any given day we are receiving in real-time six (6) Sea Surface Temperature (SST) observations per Drifting Buoy deployed. As the total global array approaches 800 Drifters we are receiving about 5000 SST observations per day.

Between 1998 and 2004:
- Transmitter lifetime[1] improved from 330 to 440 days
- SST sensor lifetime[1] improved dramatically, from 85 to >700 days
- Drogue lifetime[1] improved dramatically, from 90 to >550 days
- Deployments have increased every year while failure upon deployment has steadily decreased (12% in 1998, 5% in 2000, 3% in the last fiscal year)

[1] – median lifetime (half-life) for years 1998—2000 and 2001—2003, for all drifters that were not picked up or run aground. Drifters which stopped transmitting before SST sensor failed were not counted in SST sensor lifetime calculations, so this lifetime must be considered the half-time of the sensor, not of SST observations.

Measurements taken, where data are stored, data distribution, availability and access to data:

Observations collected include*:* Position data, sea surface temperature (SST), some sea surface barometric pressure, some wind speed and direction. Data are stored at the GOOS Center in the Global Drifter Program's Data Assembly Center (DAC). Real time data are transmitted via Argos transmitters and distributed via the Global Telecommunications System (GTS) by Service Argos and available to everyone. The delayed mode and scientifically quality controlled data are available via access to web, ftp or personal communication with the DAC within two months of collection and a copy of the data are archived at the Marine Environmental Data System (MEDS).

How data are currently being used and shared:

Drifter data are used in circulation research among several national and international oceanographic institutions. SST data are used among several national and international centers for environmental prediction (i.e. NCSP, US Navy, European Community Center for weather forecast, British and French Meteorological Offices, etc.), for ENSO monitoring and prediction and to initialize climate models. There are no restrictions on sharing this information as it is distributed in real time on the GTS.

Where the data are archived:

Drifter data are archived at the GOOS Global Drifter Program Data
Assembly Center (DAC) and at the Marine Environmental Data Service (MEDS) in Canada.

Anticipated and unanticipated project costs:

Drifter costs are declining because of improved design changes but shipping costs have increased due to late funding which required the use of air shipping rather than the less expensive ground shipping.

Problems encountered:

Three main problems arose:

1. Due to delays in disbursement of funds (funds arrived to AOML in late May), we were unable to buy and deploy a few of the drifters that were funded for FY04. These drifters will be deployed during FY05.

2. Due to war related issues, the US Navy stopped coordinating air deployments. As a consequence, all deployments are made now from ships. This limits our capability to seed regions not visited by ships (VOS or research vessels).

3. Drogue on-off status is determined from the submergence or tether strain sensor. For an increasing number of drifters, these data are extremely noisy, ambiguous or faulty such that drogue status is uncertain. We have been communicating with manufacturers to resolve this issue.

Logical considerations (e.g., ship time utilized):
The program is based on deploying the drifters through VOS and R/V available in the region. This limits our capability of filling up gaps not transited by either of these vessel types.

Research highlights:
Atlantic Drifters: The tropical Atlantic surface drifting buoy observations were used to determine time-mean near-surface currents and their seasonal variations. As a consequence of the considerable increase in data coverage due to this program and a new analysis technique developed for the data (Lumpkin and Garraffo 2004), the major pathways of near-surface currents are now resolved at unprecedented detail (Fig. 2). An analysis of the currents' seasonal variations (Lumpkin and Garzoli 2004) reveals how northern and southern hemisphere fluctuations are "communicated" via the equatorial gyre route. Ongoing extensions of this study, also heavily dependent upon the drifter observations, are examining the distribution and possible rectification of mesoscale variability and are providing estimates of the role of lateral heat advection in modulating/controlling observed SST variations.

A monthly climatology of near-surface currents and SST, derived from the drifter observations using the methodology of Lumpkin and Garraffo (2004), has been made available by the Drifting Buoy Data Assembly Center (www.aoml.noaa.gov/phod/dac/).

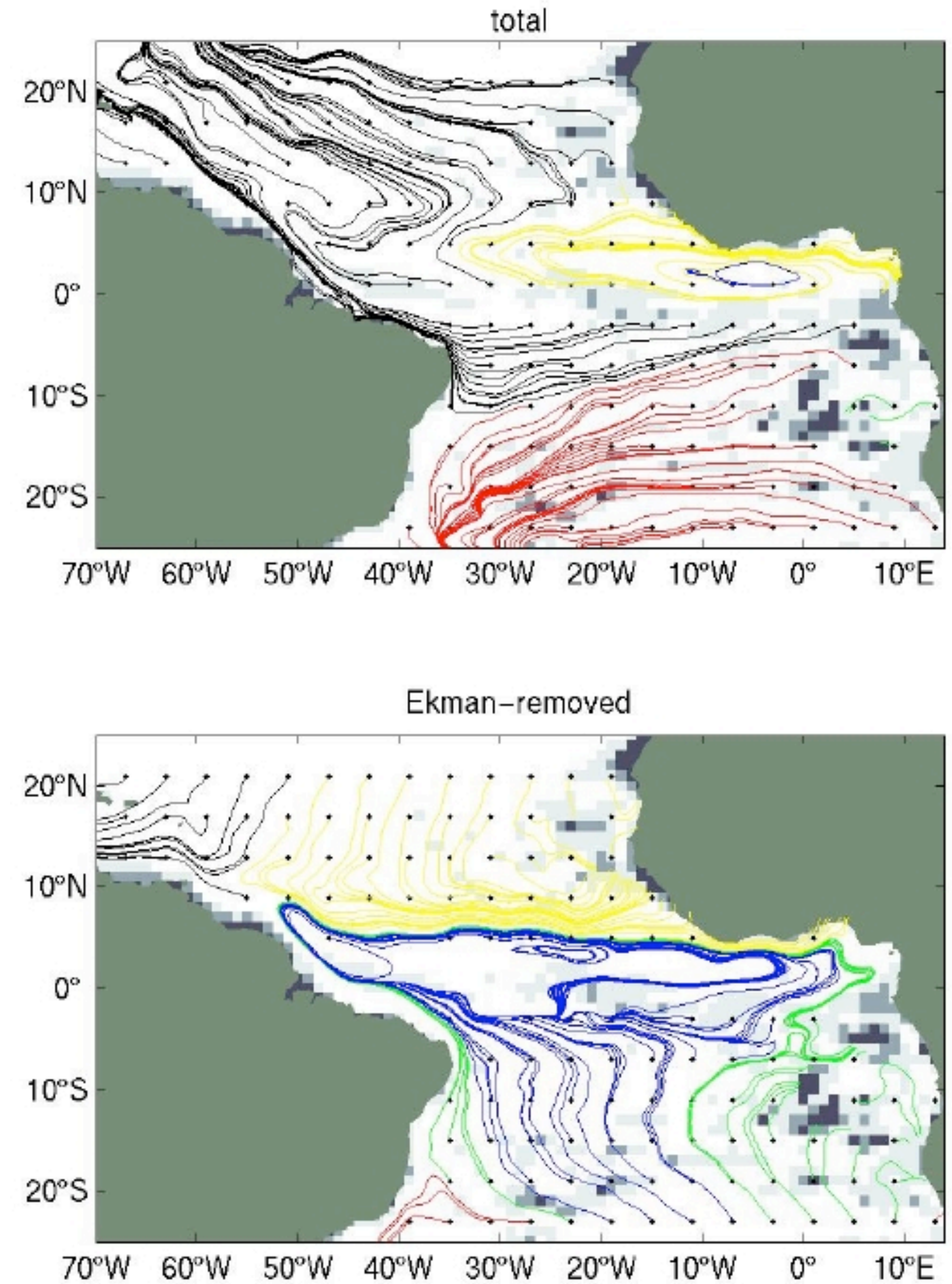


Figure 2: Pathways of advection from time-mean currents derived from surface drifter observations and visualized by integrating the currents from "release points" (black dots; see Lumpkin and Garzoli 2004 for more details). Top: advection by total currents, including the wind-driven Ekman flow. Bottom: advection by the Ekman-removed flow.

3.17a. National Water Level Program Support Towards Building A Sustained Ocean Observing System For Climate

by Stephen K. Gill and Chris Zervas

PROJECT SUMMARY

The purpose of this document is to provide a proposal for a program plan for sea level observations that could be implemented by the NOS Center for Operation Oceanographic Products and Services (CO-OPS) over the next several years in support of the NOAA Office of Global Programs Climate Observation Program. Three distinct tasks have been identified for which the NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) would provide support:

1) develop and implement a routine annual sea level analysis reporting capability that meets the requirements of the Climate Observation Program

2) upgrade the operation of selected National Water Level Observation Network Stations to ensure continuous operation and connection to geodetic reference frames

3) operate and maintain water level measurement systems on Platform Harvest in support of calibration of the TOPEX/Poseidon and Jason 1 satellite altimeter missions.

The fundamental URL's are:
http://tidesandcurrents.noaa.gov for access to all programs, raw and verified data products, standards and procedures, and data analysis reports and special reports.
http://www.co-ops.nos.noaa.gov/sltrends/sltrends.shtml for access to the latest NWLON sea level trends and monthly mean sea level anomalies.

The 10 Climate Operating Monitoring Principles are very much the same as used for the NOAA National Water Level Program (NWLP) for which the National Water Level Observation Network (NWLON) is a long-term continuous operational oceanographic network that's strives to meet NOAA's mission needs for tides and water levels. The NWLP is an end-to-end program that is planned, managed, and operated to provide products that meet user-driven needs. The program also consists of technology development, continuous quality control, data base management, and operational readiness and fully open web site for data delivery.

These data and related sea level products are made available over the web site for use by PSMSL, UHSLC, and the WOCE communities.

<u>Project Task Descriptions</u>

Task One - Routine Sea Level Analysis Reports

A Climate Observation Program Workshop was hosted by the NOAA Office of Global Programs (OGP) on May 13 - 15, 2003. The objectives of the workshop were to:

1. Initiate an Annual Program Review
2. Design a framework for regular reports on the ocean's contribution to the state of the climate and on the state of the observing system.
3. Design a framework for implementing Expert Teams to continually evaluate the skill and effectiveness of ocean products and of the observing system.

There are 18 NOAA National Water Level Observation Network (NWLON) stations identified in the International Sea Level Workshop Report (1997) as being part of the core global subset for long-term trends. The Climate Observation Program Plan calls these climate "reference stations" and includes the following performance measures for the reference stations:

1. Routinely deliver an annual report of the variations in relative annual mean sea level for the entire length of the instrumental record.
2. Routinely deliver an annual report of the monthly mean sea level trend for the past 100 years with 95% confidence interval.

The 18 NWLON stations are (in alphabetical order):

Name:	Series Length (years):
Atlantic City	90
Bermuda	59
Boston	80
Charleston	80
Crescent City	68
Fernandina Beach	104
Guam	53
Hampton Roads	74
Honolulu	96
Ketchikan	82
Key West	88
Kwajalein	55
Neah Bay	67
New York City	144
Pensacola	78
Portland	89
San Diego	95
San Francisco	150

The Climate Observation Program will be producing a second annual report on the state of the ocean and the state of the observing system for climate. It is proposed that CO-OPS produce an annual report on these reference stations that would be one section of that larger report. Over the next 3 years it is required that the report include all 62 global reference stations. The current CO-OPS report on sea level (Zervas 2001) is being used as a starting template for an annual report.

Task Two – Upgrade Ocean Island Station Operations
There are several coastal and island NWLON stations critical to the Global Climate Observing System. The operation and maintenance of the ocean island stations of the National Water Level Observation Network (NWLON) has been increasingly more difficult over time due to the slow abandonment of the island facilities at which the stations reside. Finding routine flights and flights which are cost effective are becoming increasingly difficult, yet these stations require high standards of annual maintenance to ensure the integrity of their long term data sets. Annual maintenance is even more important, in light of the fact that corrective maintenance is logistically very difficult and expensive.

Figure 1. Ocean Island NWLON Station Map.

Although operation of all of the stations is important, it is proposed that Ocean Island stations begin to be upgraded first with this funding to ensure their continuous operation (program funding and budget initiatives will be used for operation of the coastal stations). These targeted funds will be used for travel costs and for upgrade to backup systems. The upgrades will include high accuracy acoustic or paroscientific pressure sensors and redundant Data Collection Platforms (DCP's) with equal capability to the existing primary systems. The station operations will also be enhanced with GPS connections to geodetic systems followed by installation of CORS at selected sites. The following is a list of the ocean island NWLON stations (not including Hawaii) that should be considered in this category as priority for upgrade.

Station	CORS Operating
Guam	Yes
Kwajalein	Yes
Pago Pago	Yes
Wake	No
Midway	No
Adak	No
Bermuda	Yes
San Juan. PR	Yes
Magueyes Island, PR	No
Charlotte Amalie, VI	No
St Croix, VI	Yes

Task Three - Satellite Altimeter Mission Support

Support for the TOPEX/Poseidon satellite altimeter mission began with installation of an acoustic system and a digibub system on Platform Harvest in 1983 (see Fig. 2). Using reimbursable funding under MOA with JPL/Caltech, systems operations include provision of water level measurements relative to the satellite altimeter closure analysis reference frame for calibration monitoring (see B. Hanes et al, Special Issue of Marine Geodesy, 2003 "The Harvest Experiment: Monitoring Jason-1 and TOPEX-Poseidon from a California Offshore Platform".

Figure 2. Platform Harvest Calibration Site at which NOAA tide gauges are located.

CO-OPS special support has included a vertical survey on the Platform necessary to relate the water level sensor reference zeros (near the bottom catwalk) to the GPS reference zero (located up top at the helipad on the Platform. Continuous data are required to monitor effects of waves on the water level measurements and to ensure provision of data during the times of altimeter overflights every ten days. The original acoustic system was replaced by a digibub pressure system prior to the Jason-1 altimeter launch.

Platform Harvest tide gauge operations will continue with the operation of two digibub pressure systems collecting continuous water level data streams surveyed into the Platform and Satellite Orbit Reference frames. Funds will cover travel and routine an emergency maintenance and water level and ancillary sensor calibrations.

<u>FY 2004 PROGRESS</u>

Task One:

CO-OPS began the development efforts for an annual report that includes the 18 NWLON stations listed above. A tailored version of the graphics and analyses from the existing CO-OPS sea level report (Zervas, 2001) has been completed that includes the three fundamental types of analyses where data series allow. The following figures illustrate the types of analyses proposed using Honolulu as an example.

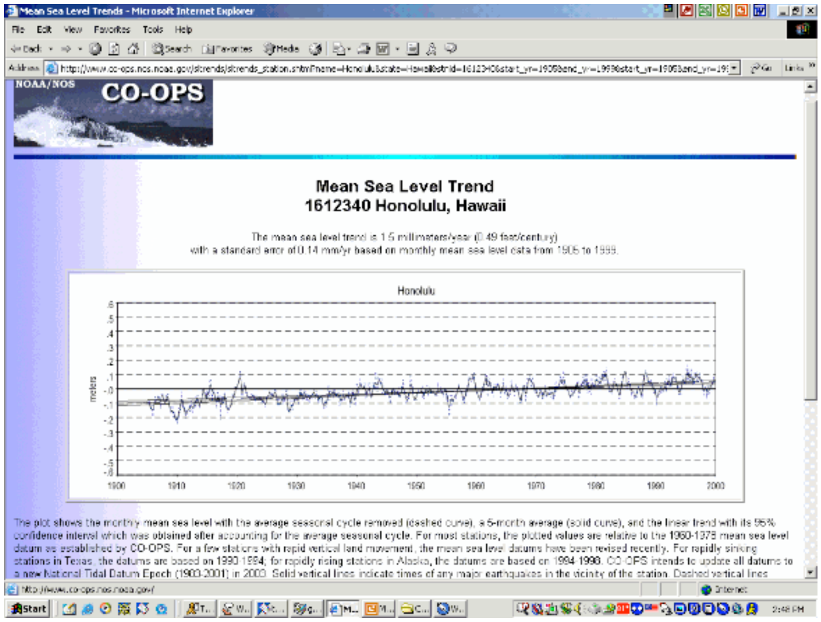


Figure 3. Sea level Trends Analyses would be updated annually.

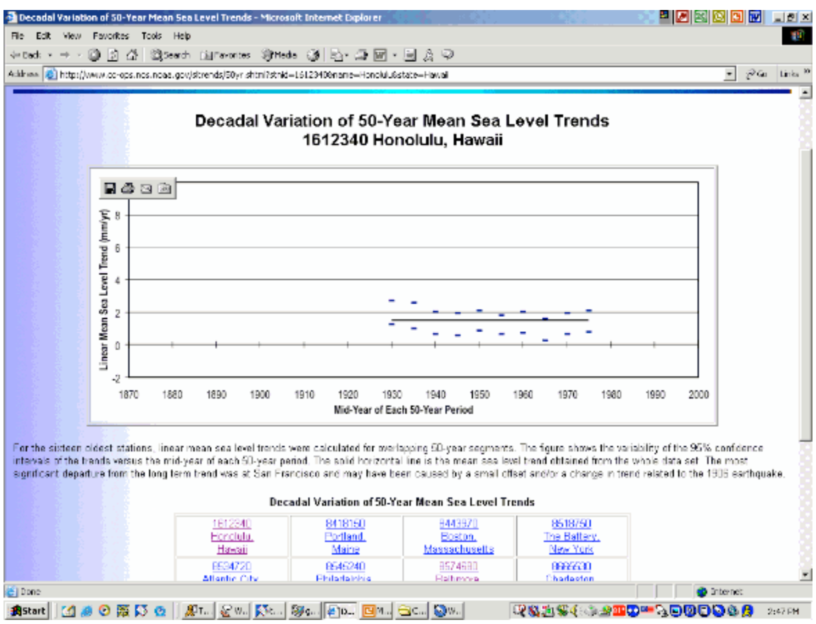


Figure 4. Long-term Variation in Trends would be routinely updated.

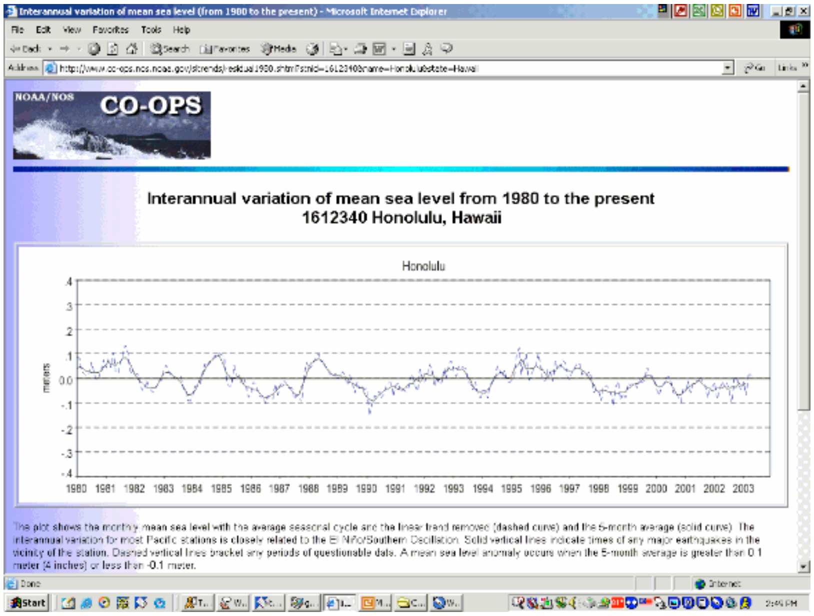


Figure 5. The Monthly Mean Sea Level variations would be updated annually.

Task Two:
Maintenance of the ocean island NWLON stations continued using FY'04 CO-OPS resource levels. Major corrective maintenance required at Guam did not take place due to Typhoon damage and backup systems were not upgraded due to lack of year-end funds. However this points to the need to have appropriate resource levels to recover from events for reference stations in general and the need to keep the records from experiencing large gaps.

Task Three:
Operation and maintenance of the station continued under MOA with Caltech/JPL. This MOA expired at the end of FY '04. Coordination of activities continues with JPL. One of the pressure systems requires repair to bring it back online, however continuous data have been maintained. JPL has arranged for underwater maintenance of the bubbler pressure system orifices.

3.18a. An End-to-end Data Management System for Ocean pCO_2 Measurements

by Steve C. Hankin, lead PI, Richard Feely, Alex Kozyr, Tsung-Hung Peng

PROJECT SUMMARY

Reliable and efficient data management within the NOAA Global Carbon Cycle Program will require standards and infrastructure to: upload/ingest new data; quality control data sets; provide users with timely access to data; and ensure its long-term archival. The October 2001 Carbon Data Management Plan, a product of the carbon data management workshop held at PMEL (Feely and Sabine 2002), articulates a community consensus on the need for a systematic approach to ocean CO_2 data management. The ultimate objective of the plan is to provide the oceanographic community with easy access to high-quality near real-time CO_2 and related physical, chemical and biological data sets. The plan outlines the need for new standards regarding analytical measurement techniques, data formats, metadata content, quality control and assessment procedures. The plan recognizes that the data management system must build upon existing capabilities and must be compatible with the emerging standards for integrated ocean data management within the U.S. It identifies the Carbon Dioxide Information Analysis Center (CDIAC) as a regional quality control and data management facility and the Live Access Server from PMEL as a sound software foundation for the system. It also recommends the creation of a CO_2 Science Team and a Data Management Group to guide the creation of standards and the evolution of the data management system.

This report "An End-to-end Data Management System for Ocean pCO_2 Measurements", is a road map for the implementation of that data management plan as an end-to-end data management system, and a process for governance of that system under the CO_2 Science Team. The vision of the data system is of five integrated components coordinated through a suite of data standards and procedures. The components are i) local QA/QC and the initial collation of shipboard data; ii) regional QC and assembly of data and metadata; iii) operational data base management; iv) the Web-based data and metadata access subsystem; and v) permanent archival. The partners in the development of this solution are NOAA/PMEL, CDIAC and NOAA/AOML.

The Carbon Data Management (CDM) system that is under development through this proposal is an essential component of NOAA's Program for *Building a Sustained Ocean Observing System for Climate*. The CDM approach will utilize the standards and protocols advocated by the emerging Data Management and Communications (DMAC) subsystem of the US IOOS. As such the CDM will be fully compatible with the data and assimilation systems that will deliver routine ocean analyses through the international Global Ocean Data Assimilation Experiment (GODAE). It will be similarly integrated with the international ocean data frameworks, the Observing System Monitoring Center (OSMC), the US GODAE Server and its climate data-serving partner the Asia Pacific Data Research Center (APDRC) through the National Virtual Ocean Data System (NVODS).

The data management principles that are integrated into the CDM system design are in accordance with the Ten Climate Monitoring Principles requires:

- The need for data management systems that facilitate access, use, and interpretation of data and products;
- A fully integrated approach that embraces both data and metadata management including details and history of local conditions, instruments, operating procedures, data processing algorithms, and other factors pertinent to interpreting data;
- Continual assessment of the quality and homogeneity of data; and

- Flexible access to data through multiple protocols and formats making it readily usable in the creation of environmental and climate-monitoring products and assessments.

Work on the CDM system began only in March of 2004, so many of its capabilities are not yet available for access through a stable Web site. The initial URLs for the CDM are

- http://cdiac3.ornl.gov/underway/servlets/dataset
  -- initial carbon data access via LAS
- http://mercury.ornl.gov/ocean/
  -- initial carbon metadata access via Mercury
- http://www.ferret.noaa.gov/Ferret/LAS/CDIAC_LAS/
  -- database design discussion and documentation

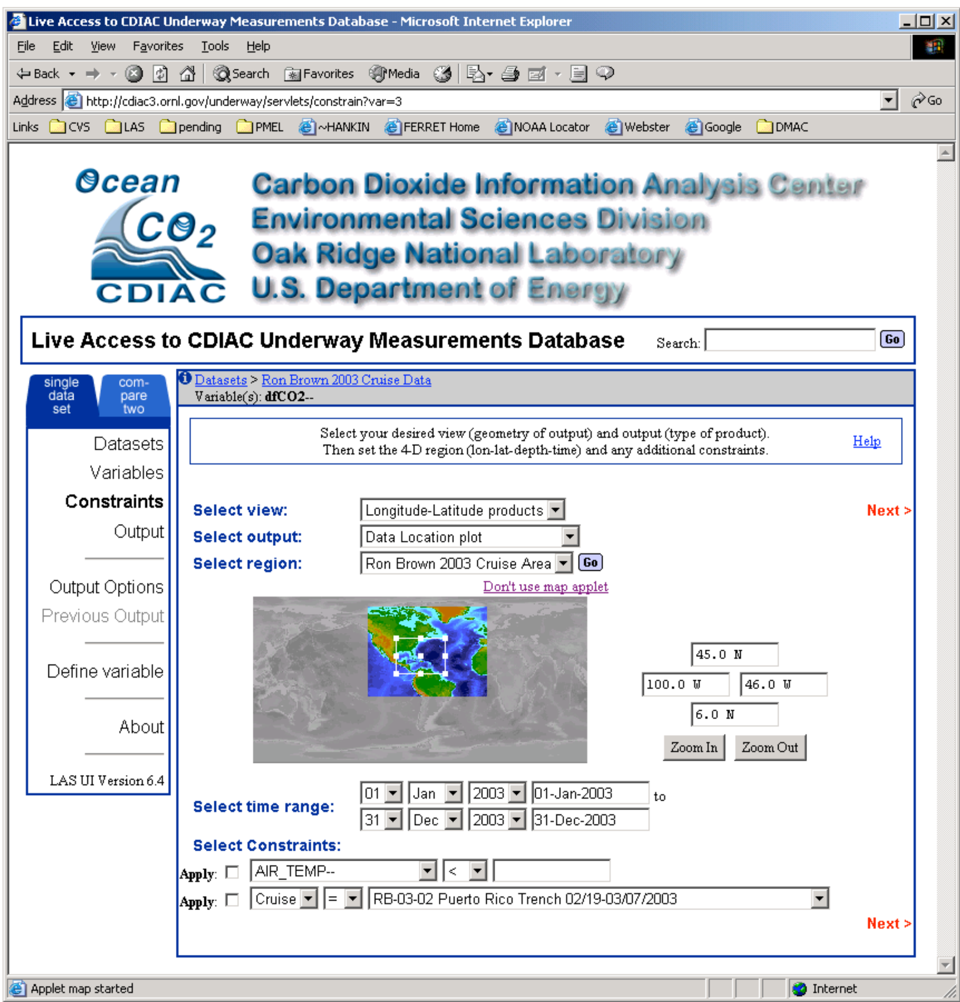


Figure 1. Underway CDM user interface.

FY 2004 PROGRESS

Since the start of work on the CDM system began in March of 2004 the following milestones have been achieved:

PMEL Accomplishments:

1. A new software developer Yonghua Wei, with a high level of expertise in database design, was recruited for the PMEL CDM development team;
2. PMEL designed an initial relational database management system (RDBMS) schema that will accommodate the data storage and access requirements for underway data generated by the carbon community. This work is documented at the URL previously given in the Project Summary;
3. Scripts were written to ingest ASCII-formatted cruise data files from CDIAC into the RDBMS;
4. Underway data from CDIAC (the Ron Brown 2003 cruises) was used to populate an initial version of the database. An initial Live Access Server (LAS) was configured with one year's worth of Ron Brown cruise data;
5. PMEL created a synthetic database representative of the size of the mature CDM system to test performance and operations. Tests with over 500 MBytes of synthetic data indicate that the current database schema will efficiently subset data based upon realistic time and space constraints.
6. Jon Callahan of PMEL traveled to CDIAC to install the new underway database and configure an underway LAS.

Examples of the user interface design and initial output products are shown in Figures 1 and 2.

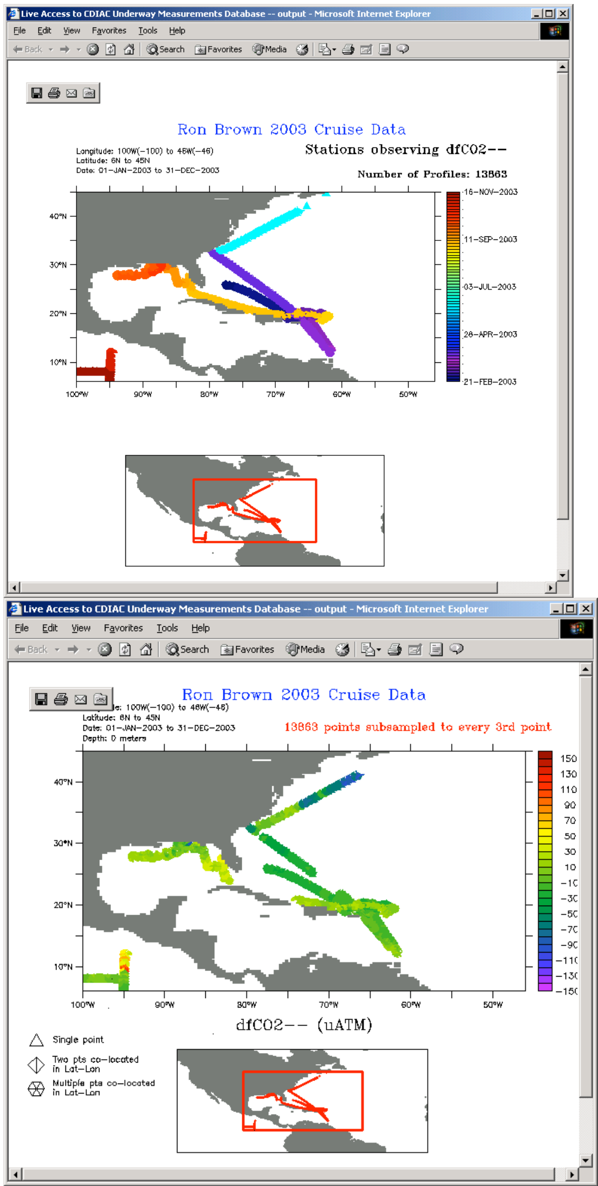


Figure 2. Prototype plots obtained from LAS to visualize (left) the available data within a specified time-space region and (right) the measured values

CDIAC Accomplishments:

1. CDIAC has been developing a web page for VOS data management work with links to the data. The web page is under construction at this time, however it is linked from the CDIAC Ocean home page at: http://cdiac.ornl.gov/oceans/home.html as "VOS Project Data". The VOS web page will include a map with past and future (planned) cruises on Volunteer Observation Ships. These clickable maps will link to the data files for each cruise/VOS route.

2. CDIAC established a prototype system to search for ocean metadata and retrieve associated underway and ASCII bottle data utilizing the Mercury system. The link to CDIAC Ocean Data Mercury: http://mercury.ornl.gov/ocean/. Mercury incorporates a number of important features:

- Implements a dynamic, distributed approach to scientific data and metadata management;
- Puts control in the hands of data providers (carbon science investigators);
- Has a very "light touch" (i.e., is inexpensive to implement);
- Is implemented using Internet standards, including XML;
- Supports international metadata standards, including FGDC;
- Is compatible with Internet search engines; and
- Is based on COTS software, including Blue Angel Technologies' MetaStar® products and Hummingbird's Fulcrum SearchServer®.

3. With help of Jon Callahan and Yonghua Wei of PMEL CDIAC opened the first Live Access Server for underway carbon data at: http://cdiac3.ornl.gov/underway/servlets/dataset. The Underway LAS is open for public access with the Ron Brown 2003 Cruises Data as an example. The data management utilizes the content standard that was established during the Workshop on Ocean Surface pCO_2, Data Integration and Database Development. Tsukuba International Congress Center, January 14-17 2004 (http://ioc.unesco.org/ioccp/Tsukuba2004Results.htm).

4. Alex Kozyr of CDIAC delivered above accomplishments at the VOS Underway Data Science Team meeting at the University of Miami on October 6, 2004.

AOML Accomplishments:

As outlined in the proposal AOML has focused on instituting uniform data reporting formats and quality control procedures. At a meeting at Lamont Doherty Earth Observatory in September 2003 agreement was reached on a data format and content standard that will be used for all NOAA underway pCO_2 ship data. This format with slight modification and appropriate, uniform metadata content was adopted as the recommended protocol for the International Ocean Carbon Coordination Project (IOCCP) in Tsukuba, Japan, January 2004.

Our current data are processed in this format with the parameters listed in Table 1. The parameter list is comprehensive in the sense that an outside investigator can recalculate the pCO_2 and perform screening based on meteorological conditions, and ship's speed and location. Quality control flags are included for the water and air pCO_2 measurements. The data that have undergone "local" quality control is posted on our web site, http://www.aoml.noaa.gov/ocd/gcc, generally within one to six-months after receiving the data from the ships.

Table 1. Parameters to be included in surface water pCO_2 files as recommended by the IOCCP and adopted by the NOAA VOS group.

GROUP/SHIP	xCO2A_PPM
CRUISE_DESIGNATION	PRES_EQUIL_hPa
JD_GMT	PRES_SEALEVEL_hPa
DATE_DDMMYYYY	EqTEMP_C
TIME_HH:MM:SS	SST(TSG)_C
LAT_DEC_DEGREE	SAL(TSG)_PERMIL
LONG_DEC_DEGREE	WATER_FLOW_L/MIN
xCO2W_PPM	GAS_FLOW_IR_ML/MIN
TEMP_IR_C	fCO2A_uATM

PRES_IR_hPa	QC_FLAG_AIR
SHIP_HEADING_TRUE_DEGREE	dfCO2_uATM
SHIP_SPEED_KNOT	FLUORO_uG/L
WIND_DIR_REL_DEGREE	WIND_SPEED_TRUE_M/S
WIND_SPEED_REL_M/S	WIND_DIR_TRUE_DEGREE
fCO2W@SST_uATM	AIR_TEMP_C
QC_FLAG_WATER	

As part of this project we are also reformatting our historical data and providing the metadata in the agreed-upon format. Data from the NOAA ship MALCOLM BALDRIGE starting 1991 through 1995 has recently been posted on the website listed above. The 2003 data sets from NOAA ship BROWN were imported successfully into the LAS system developed in this project – a validating test for the new data formats.

3.19a. Observing System Research Studies
by D. E. Harrison

PROJECT SUMMARY

This project supports the design and development of the global ocean observing system for climate through a variety of data analysis and modeling studies, intended to expand our knowledge about what we know and what we cannot know from the observing system as deployed and the historical data set that has been produced over the decades. It also supports the evolution of the observing system through evaluation of alternative observing strategies and evaluation of the differences between available ocean analysis products (taken as one measure of the uncertainty in the analysis products). Finally it supports the Office of Climate Observation and NOAA's observing strategy through the PI's activities as Chair of the Ocean Observation Panel for Climate (co-sponsored by the GOOS, GCOS and WCRP) and other sustained ocean observing leadership activities.

Initial focus has been on SST variability since it is agreed to be the most important variable for climate impacts. Work with other variables will be expanded in the coming year as described below.

FY 2004 PROGRESS

Overall, the work of the group provided a variety of scientific and social impact justifications for continuing the deployment of the planned global climate observing system, and continued to define the space and time scales of observations needed for specific phenomena that must be accurately observed.

The Indian Ocean remained a focus of activity, because NOAA plans to extend the tropical mooring array into this ocean in FY05. Indian continental rainfall and its dependence on SST anomalies is one of the primary societal impacts, as almost one billion people depend on the Southwest monsoon's rainfall. The Vecchi and Harrison paper is the first, to our knowledge, to establish a firm connection between Indian SST anomalies and Indian continental rainfall. What made this discovery possible was recognizing that All-India Rainfall (AIR), the most widely used measure of Indian rainfall, is the sum of two non-correlated regional rainfalls. When correlations are sought between SST and the two different regions, relationships exist even though there are not significant correlations between AIR and Indian SST.

This result provides one path to link ocean observations and process studies to a major societal impact. The equatorial waveguide is not the region that should get priority, unlike the tropical Pacific. The strongest relationship is between western Indian rainfall and SST variability in the Arabian Sea in the months preceding the onset of the SW monsoon. Whether there is predictability for these Arabian Sea anomalies needs to be explored further.

Unpublished work on Indian Ocean SST is well advanced as this is written. Subtropical SST anomalies have been linked to eastern African rainfall anomalies, but the mechanisms responsible for these anomalies (and, hence, their predictability) remains controversial. One of the major instances of this connection occurred in the 97-98 El Nino; it remains to be seen if the connection is primarily an El Nino connection or if other processes may be at work. Exploring these questions will be part of Chiodi's Ph.D. thesis work. Chiodi has already discovered a new mode of summer subseasonal southern hemisphere SST anomalies, which are not well resolved in the Reynolds/Smith SST analysis. Work will continue in the characterization of these anomalies, the challenges posed to the observing system to resolve them properly and to understand the processes responsible for them (in order to explore their predictability).

The TRMM TMI SST data set, based on microwave SST retrievals has been essential in the Indian Ocean work, because it permits observation of SST anomalies under many types of cloudy conditions. SST is not observable by IR techniques under these conditions. The work of this project thus makes a strong case for the importance of continuing access to TRMM quality microwave SST information as a component of the global ocean observing system.

Work on equatorial Pacific SST variability also continued during FY04. Previous work into the relationships between westerly wind events (WWE), the Madden-Julian Oscillation (MJO) and waveguide SST warming has been updated. The relationships that were found previously, but which were of marginal statistical significance are now clearly statistically significant. They establish that WWEs are no more likely to occur during an MJO than they are when an MJO is not present, that waveguide warming follows the passage of an MJO only when a WWE occurs during the MJO but that WWEs, if they occur during an MJO, are more likely to occur during the convective phase of the MJO. Together with the earlier published work that establishes a dynamical connection between WWEs and waveguide warming, this work strongly suggests that observing and predictive attention should be given to WWEs and not to the MJO, if El Nino prediction is the objective. High time resolution observations are essential to proper characterization of WWEs; the TAO/Triton moorings remain key to this capability.

Predicting the termination of El Nino events is another objective of NOAA's seasonal to interannual prediction efforts. Via a series of ocean numerical model studies, the processes responsible for the termination of the 1997-98 and 2002-03 El Nino events have been identified. In each case the mechanism appears to be that proposed by Harrison and Vecchi (1999), in which the coupled interaction between the seasonal meridional cycle of solar insolation and near-equatorial SST anomalies, and the zonal wind anomalies associated with the resulting SST anomalies near the Dateline, is key. Delayed oscillator processes are not necessary to account for the observed oceanic behavior. The state of cold tongue zonal winds at the height of the El Nino determines whether the oceanic response to the zonal wind anomalies will lead to termination of the El Nino in early spring (as happened in 2002-03), or if the El Nino will continue into late spring (as happened in 1997-98 and 1982-83). Again, accurate near-equatorial wind and SST knowledge, such as is obtained from the TAO/Triton array, is key to successful prediction.

Work has also continued in the use of TAO/Triton data to test existing models of the equatorial Pacific. It has been found that the Gent/Cane intermediate model cannot be reconciled with the observations, when used with the limited vertical resolution that has been adopted so far in model studies using this formulation. The mooring data have been essential to this study, providing an important result for the relevance of intermediate coupled models for study of El Nino predictability and processes.

The importance of high latitude information for US seasonal weather anomaly forecasting has been given a new twist by our discovery that the weather anomalies, particularly over the eastern half of the US during an El Nino winter depend on the sign of the Arctic Oscillation (AO). Further we have found that there is a reasonable statistical basis for Winter AO forecasting, given knowledge of autumn AO conditions. We have communicated this result at national meetings and to L. Uccelini. Accurate knowledge of the AO thus appears key to improved US winter weather forecasts. It may be that improved knowledge of MSLP over the Arctic will lead to improved understanding of the AO and improved means for its seasonal prediction.

The MJO is useful for forecasting certain U.S. West Coast weather anomalies, as we have shown in two publications. One addresses winter flooding events in the Pacific Northwest and the other major winter warm episodes in Alaska. For these applications, improved ability to forecast the MJO is needed. Present thinking seems to be that improved information about air-sea interaction in the Indian Ocean is needed for better understanding of the predictability of MJO events. Thus expansion of the ocean observing system into the Indian Ocean is called for.

A new project, undertaken with Mark Carson (graduate student at University of Washington) is examination of the subsurface temperature trends in the World Ocean Data Set prepared at NODC. Because recent work with this data set and sea level gauge data suggested that interpolation of the ocean data could lead to incorrect inferences about subsurface heat changes, we have taken a different approach. We identify the one-degree grid boxes with the best data distribution over the post-WWII period and evaluate the temperature trend over each box. No interpolation in space or time is done; neither is any ocean climatology removed from the temperature observations. The primary uncertainty source in our approach is inhomogeneity of the observing technology (MBTs to T4 XBTs to T7 XBTs); we have not determined yet if NODC has made corrections for known fall-rate differences between T4 and T7 probes. Taking the observations as given from NODC, we find that the 50year trends at 100m, 300m and 500m vary considerably from basin to basin and from one gyre to another. In some regions there is cooling; in others there is warming. There is no tendency to basin scale warming in each ocean, as has been suggested in studies using an interpolated version of the data set. Additional work needs to be done, but the present results strongly suggest that the existing ocean subsurface data set is not adequate for the determination of subsurface multi-decadal basin averaged trends. This clearly indicates the importance of global deployment and maintenance of the Argo profiling float array, if ocean subsurface trends are to be known accurately in future decades.

3.20a. Teachers at Sea

by John Kermond

PROJECT SUMMARY

The NOAA Teacher at Sea (TAS) program started in 1990, is managed part-time from Seattle, WA, and more than three hundred teachers participated between 1990 and 2004.

The Aerosol Characterization Experiment –Asia (ACE-Asia) in 2001 saw the introduction of a new TAS category – a sponsored teacher. The NOAA Office of Global Programs (OGP) pioneered this new program with support from program managers within the office.

Consistent support for teachers at sea has come from the Office of Climate Observation (OCO). Either alone or in partnership with other OGP programs, as well as with the National Science Foundation, OCO has provided funding for teachers (both national and international) to participate in programs such as the Tropical Atmosphere Ocean Array (TAO), the Eastern Pacific Investigation of Climate (EPIC), the South American Low Level Jet Experiment (SALLJEX), Climate Variability (CLIVAR), the North American Monsoon Experiment (NAME), and STRATUS cruises.

Supported teachers have brought a new dimension of education and outreach to NOAA. Their daily logs, lesson plans, email responses, digital pictures, and live web broadcasts have brought both the fundamental and the cutting-edge science of the agency to global audiences. This has contributed mightily to the NOAA-wide goal of enhanced literacy in both oceanic and atmospheric matters.

With TAS program management now full-time and centrally coordinated, the program is going from strength to strength – something not un-noticed by lawmakers on Capitol Hill, in Washington, D.C. Representative Vern Ehlers (R-MI) remarked in regard to the TAS program "I do not know what you spend on this program, but you really should triple it – and I will help you find the money".

Even the modest financial support for the TAS program has brought with it some remarkable technological breakthroughs. Live web broadcasting from NOAA ships; the move from indoor broadcasting to outside on the decks (and with it live ship operations); the captioning of the broadcasts for the hearing impaired; broadcasting in foreign languages (both Japanese and Spanish); and from both the northern and southern hemispheres. The supported TAS program has seen teachers in Chile, Bolivia, Japan, South Korea, the Galapagos Islands, Nuku Hiva in the French Marquesas, Mexico, and as far north as Alaska and as far south as Punta Arenas at the tip of South America.

Teachers and their classes have adopted TAO buoys; they have adopted drifting buoys (a new program element started in December of 2004 and sponsored by the Office of Climate Observation); and in March of 2005 the first children's book will be published based on a cruise supported by OCO. Written by TAS Mary Cook and former TAS Diane Stanitski, this book will be given to teachers at the National Science Teachers Association (NSTA) annual meeting in Dallas, TX.

Information on the TAS program can be found at www.tas.noaa.gov, and also at www.ogp.noaa.gov.

3.21a. Progress Report For the Observing System Monitoring Center (OSMC)

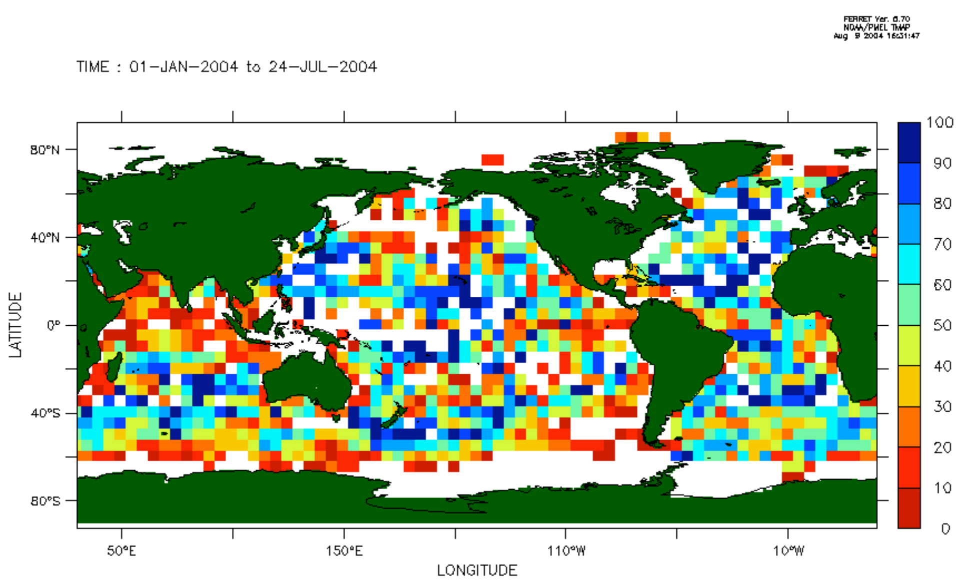
by Kevin J. Kern and Steven Hankin

PROJECT SUMMARY

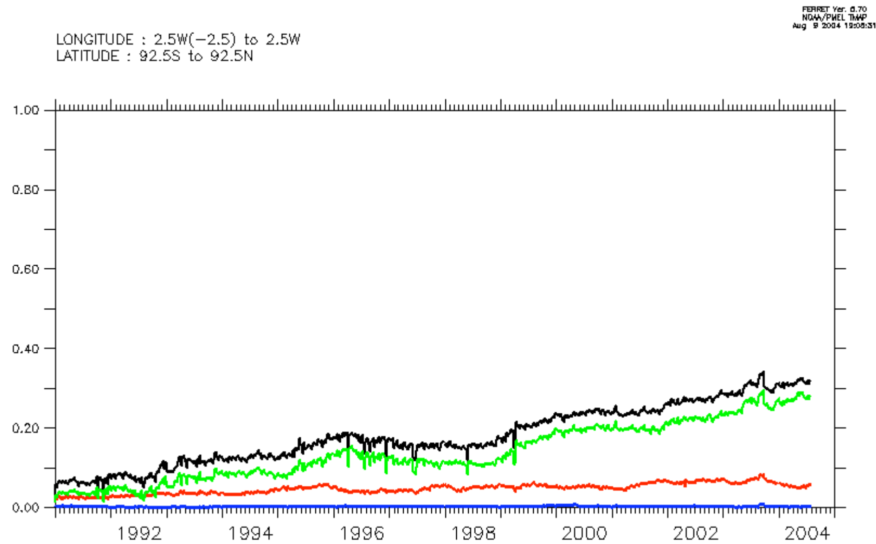
The Observing System Monitoring Center (OSMC) system is an information gathering, decision support, and display system for the National Oceanic and Atmospheric Administration's (NOAA) Office of Climate Observations (OCO) located in Silver Spring, MD. The OSMC system displays current and historical status of globally distributed meteorological and oceanographic data collection systems. The OSMC system provides data visualization tools to identify the coverage of any given collection of platforms and parameters. These visualization tools are available via the internet and can be used to present information from OSMC to other NOAA centers, national partners, and international partners. The OSMC system can be accessed through the use of a conventional web browser (i.e. MS Internet Explorer). The system can be accessed by following the links from the OCO Web page (www.oco.noaa.gov) or accessed directly at the following URL: http://osmc.noaa.gov/OSMC/.

The OSMC project is a joint development effort between the National Data Buoy Center (NDBC) located at Stennis Space Center in Mississippi and the Pacific Marine Environmental Laboratory (PMEL) located in Seattle Washington. Funding is provided by OCO under the direction of Mr. Mike Johnson. The project is aligned to take advantage of the strengths of each organization. NDBC (an operational organization) is responsible for the data, while PMEL (a scientific organization) is responsible for the user interface/graphics/analysis tools. PMEL has taken advantage of their existing tools Live Access Server (LAS), and Ferret (a data visualization and analysis tool) in the development and support of OSMC. NDBC has leveraged its investment in Oracle to support the OSMC database.

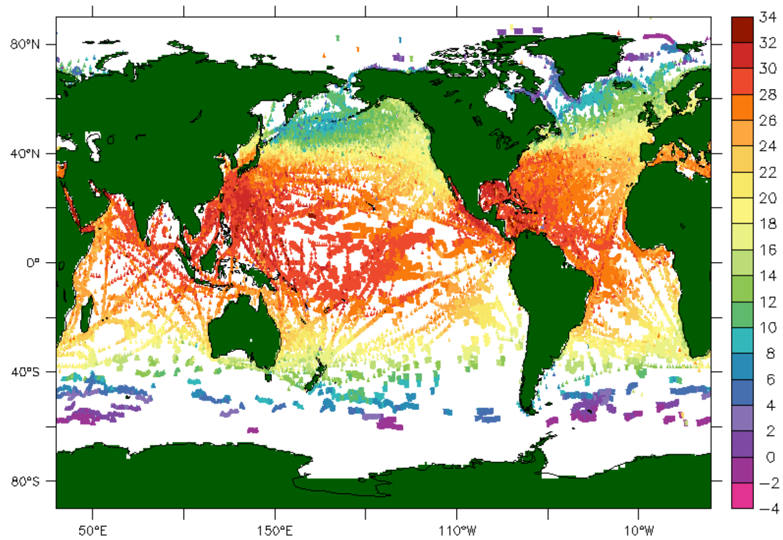
The following provides sample displays from the current OSMC system.



Percent of Weeks with 25 Accuracy Weighted sst obs in 5x5 Box 2004



Fraction of 5x5 Ocean Boxes with 25 Weekly Accuracy Weighted sst obs



All SST Observations jul 2004

FY 2004 PROGRESS

The following progress was made on OSMC during fiscal year 2004.

- Continued the development and updating of project documentation. The documentation includes: Architecture Design Document, Data Management Software Requirements Specification, Database Design Document, and the User Interface Specification.
- Installed the hardware/software to support OSMC at NDBC in time to support the OCO Climate Workshop held in April 2004. This included configuring the web server, installing the LAS software, installing Ferret software and installing the OSMC Executive Interface software. In addition, network devices controlled by NDBC and NASA had to be updated to allow the flow of OSMC traffic through the network.
- Continued updating the gridded observation tables and the (pre-created) high performance graphics available through the Executive User Interface on a monthly basis.
- Made improvements to the user interface of the OSMC software and to the output products of OSMC like the smooth filled contoured plots, displaying each plot in a separate browser window, displaying the "information" page in a separate window, etc.
- Created prototypes of new animations using ship tracks, drifter tracks and moored buoys.
- Created a "mockup" GIS-style User Interface for OCO to be reviewed and solicit comments. Supported a meeting between OCO, PMEL, and NDBC to discuss User Interface design options.
- Creating a linkage that grants PMEL developers direct access to the OSMC database in Oracle at NDBC. This linkage is key to efficient, parallel, collaborative software development between PMEL and NDBC.
- Developed and presented an OSMC overview poster at the Climate Observation Program Review and the Technical Science Workshop. Also created a kiosk-style PowerPoint slide presentation of the poster contents for presentation on the OSMC display screens. Presented a live demonstration and discussion of the system at the OCO Open House. A sample of the poster is included in Appendix A.
- Developed the initial OSMC Oracle database. Defined the schema, loaded initial lookup/verification tables with data extracted from other systems, and began processing the GODAE T-files on a daily basis starting 1 June 2004. The database is being populated at a rate of over 20K new entries each day – updated daily. The entity relationship diagram for the database is shown in Appendix C.
- Developed programs to update the NetCDF files accessed by the Executive User Interface with the data that is written to the Oracle database during the daily updates.
- Supported various OCO meetings including the Climate Observation Program Review and the Technical Science Workshop in April, the Etienne Charpentier meeting in January, and other technical/design meetings. NDBC and PMEL also conduct a technical exchange conference call weekly to discuss the OSMC project.
- Updated OSMC to use the latest version of LAS v6.2.
- Working with OCO to support the Adopt-A-Drifter program.
- Paper on OSMC submitted to and accepted by the American Meteorological Society. Presented an OSMC poster at the AMS meeting in January 2004 in Seattle.

Appendix A – OSMC Poster

THE OBSERVING SYSTEM MONITORING CENTER:

A TOOL FOR THE MONITORING AND EVALUATION OF THE GLOBAL OCEAN OBSERVING SYSTEM

Steve Hankin[1], Kevin O'Brien[2]

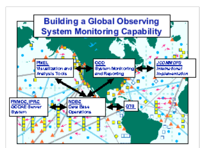
Landry Bernard[3], Don Conlee[3], Kevin Kern[3]

[1] NOAA/Pacific Marine Environmental Lab [2] University of Washington/JISAO

[3] NOAA/National Data Buoy Center

OSMC Background

- There is a clear need for a system that provides a full view of the global ocean climate observing system
- The intent of the OSMC is to create a decision support tool for NOAA that shows the gaps and overlaps in the observing system
  - Accessed via Internet
  - Displayed on large-panels in OSMC briefing room

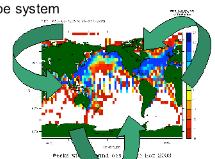


- A useful tool for users throughout the ocean community
  - Assessment of data for assimilation into models
  - Improve understanding of data product limitations
- Initial Operational Capability in late 2004
- Full Operational Capability in late 2005

Software Development Approach

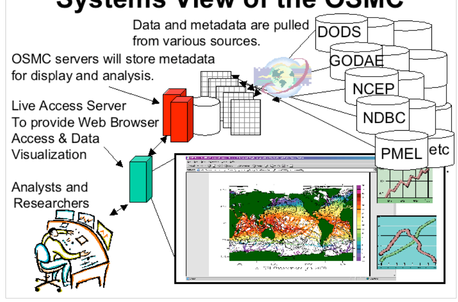
Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington develops prototype system

NOAA Office of Global Programs (OGP) in Silver Spring, Maryland requests changes & features



National Data Buoy Center (NDBC)at Stennis Space Center, Mississippi hosts OSMC servers and performs metadata management

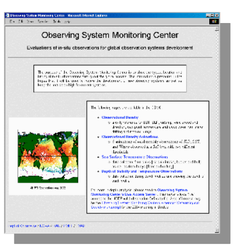
Systems View of the OSMC

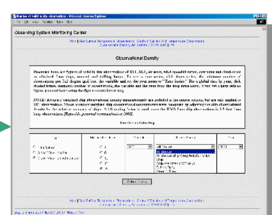


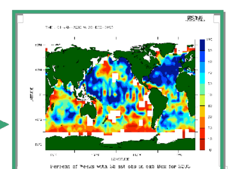
Current OSMC Capabilities

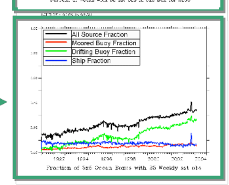
Available from *http://www.oco.noaa.gov*

"Executive" User Interface (standard products)

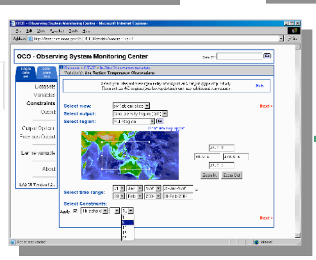


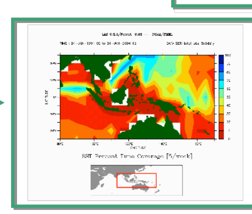




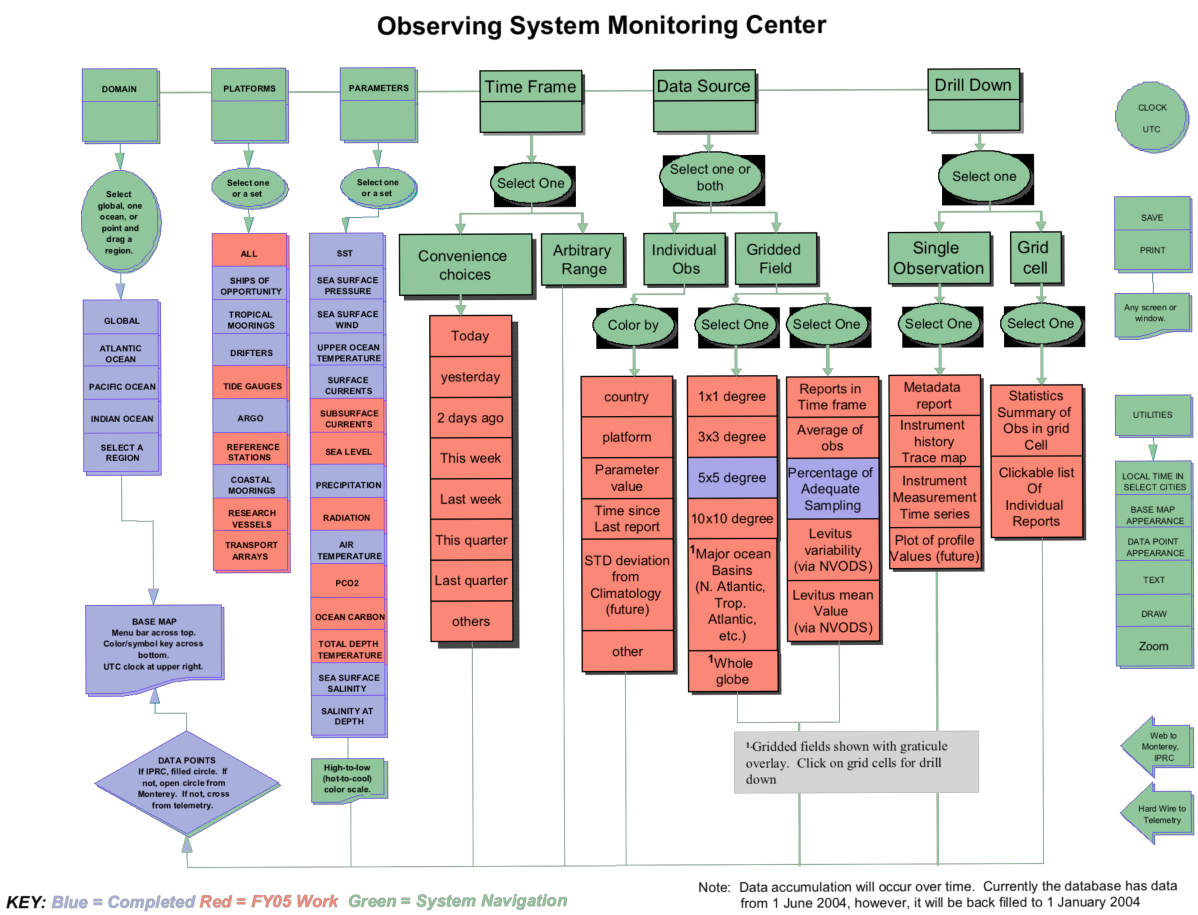


Live Access Server (a probe to look deeper)



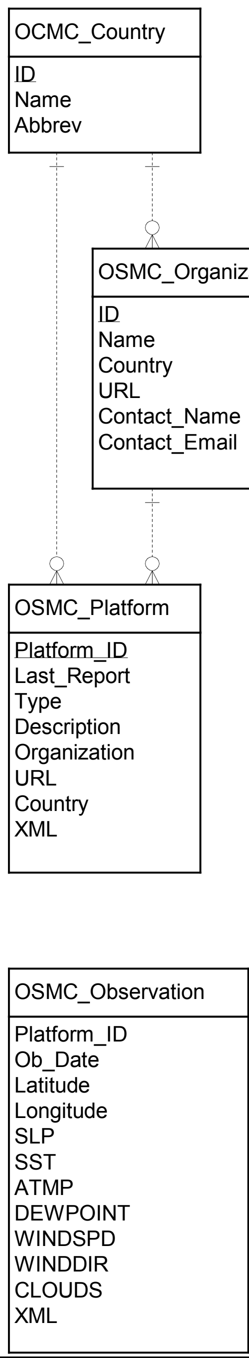


Appendix B – OSMC Revised Bubble



Appendix C – OSMC Entity Relationship Diagram

OSMC Database	Edit Date: 6/4/2004 1:26:30 PM	
Description: This is the proposed database layout for the Observing System Monitoring Center.		
Target DB: Oracle	Rev: 1.2	Creator: Bill Smith
Filename: OSMC_Database_Structure.vsd		Company: NDBC/SAIC



3.22a. An Indian Ocean Moored Buoy Array For Climate

by M.J. McPhaden

PROJECT SUMMARY

This continuation proposal requests funds to maintain 3 mooring sites in the equatorial Indian Ocean as part of a fledgling Indian Ocean moored buoy array. This work is a contribution to NOAA's effort to "Build a Sustained Ocean Observing System for Climate" and supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." The array is part of a multi-national effort within the context of the Climate Variability and Predictability (CLIVAR) research program to improve our understanding of the Australian-Asian monsoon and its far field impacts. Management of this array is consistent with the "Ten Climate Monitoring Principles". Program oversight at the international level is through the CLIVAR/GOOS Indian Ocean Panel (IOP) and the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A web site for data display and access is under construction. An Add Task to expand this fledgling array to 6 sites is appended to this proposal.

Background:

The US Climate Change Science Program has identified the critical need for the federal government to begin delivering regular reports documenting the present state of the climate system. As stated in the *US Climate Change Research Initiative* (CCRI, 2002), long-term monitoring systems are the foundation for research, modeling, and informed decisions. Yet an observing system capable of accurately documenting the full range of climate variability and change does not presently exist, especially for the oceans.

Much of the natural variability observed in the climate system originates in the tropics where heat from the sun enters the ocean. This heat is exported to higher latitudes on long time scales to moderate the Earth's mean climate. On shorter interannual to decadal time scales, ocean feedbacks to the atmosphere influence patterns of global weather variability through teleconnections such as those associated with El Niño and the Southern Oscillation (ENSO). The advanced understanding of the role of the tropics in forcing mid-latitude weather and climate was learned primarily through the observations of the tropical moored buoy array (TAO/TRITON) in the Pacific. A similar pilot array in the Atlantic basin (PIRATA) now offers the potential of even better understanding, improved forecasts, and improved ability to discern the causes of longer term changes in the oceans and their remote impacts over the US. The addition of an Indian Ocean array will complete the moored component of a tropical ocean observing system.

The Indian Ocean influences the dynamics of the Indian and Asian monsoons. It also remotely affects the climate over the US and North America via monsoon-ENSO interactions and via atmospheric intraseasonal oscillations which are spawned over the Indian Ocean. The Indian Ocean is much less well sampled than either of the other two tropical basins however, resulting in serious limitations in the ability to predict seasonal-to-interannual climate variability. Thus, international planning efforts assign a high priority to establishing a comprehensive *in situ* observing system in the Indian Ocean as part of the Global Ocean Observing System (GOOS), the Global Climate Observing System (GCOS), and the World Climate Research Program's Climate Variability and Predictability (CLIVAR). As in the two other tropical basins, a broad scale Indian Ocean moored buoy array will form the cornerstone of systematic *in situ* ocean measurement efforts designed to improve description, understanding, and prediction of large ocean-atmosphere interactions and their influence on regional and global climate.

The goal of this effort is to develop a moored buoy array in the tropical Indian Ocean in concert with other observing system components such as the Argo floats, surface drifters, SOOP measurements, times series reference stations, tide gauges, and satellite remote sensing. Coordination at the international level is through the newly formed CLIVAR/GOOS Indian Ocean Panel and the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel. In addition to providing data for understanding and forecasting physical climate variations, moorings of the array can provide platforms for supporting instrumentation to measure carbon dioxide and other parameters essential for understanding the global carbon balance, biogeochemical cycles, and marine ecosystem dynamics. Thus, the array will support the development of improved climate analysis and prediction products of use to NOAA managers, policy makers, and the general public.

FY 2004 PROGRESS

The first meeting of the CLIVAR/GOOS IOP was held in Pune, India, in February 2004. The PI of this proposal is a member of the IOP and lead the effort to develop a draft plan for an Indian Ocean moored buoy array. The proposed array includes 36 surface moorings, 9 of which would have full air-sea flux measurement capability, and 5 subsurface ADCP moorings (Fig. 1). Two of the surface moorings sites and one of the ADCP sites have already been occupied by JAMSTEC along 90°-95°E. A full discussion of the scientific rationale for the array, as well as other elements of a proposed Indian Ocean observing system for climate, can be found in the IOP strategy document at
ftp://ftp.marine.csiro.au/pub/meyers/Implementation%20Plan/.

During the meeting the PI identified an opportunity for early initial deployments from a cruise planned for September 2004 on the Indian *RV Sagar Kanya*. He then wrote a proposal with scientists from India's National Institute of Oceanography (NIO) to seek 5 days of ship time for the deployment of 3 ATLAS moorings along 80.5ºE at 1.5ºN, 0º, and 1.5ºS, and a subsurface ADCP mooring near the equatorial site. While awaiting official approval of the ship time request, the TAO Project began procuring equipment, assembling moorings and planning logistics in March 2004. The necessary mooring equipment was mostly purchased with FY 2004 funds provided by the Office of Climate Observation. However, we took advantage of equipment left over from the recently completed EPIC program in the eastern Pacific to increase available inventory. This augmentation proved to be very advantageous, as it allowed us to send a spare system as described below.

We were notified of tentative cruise dates and ports in mid-June, and made shipping and travel arrangements based on this information. In mid-July we received formal notification that the ship time request was approved, along with a start date of October 4. The shipment of mooring equipment left Seattle shortly thereafter, to arrive in India a month before the cruise, which was presumably sufficient time to clear Indian Customs.

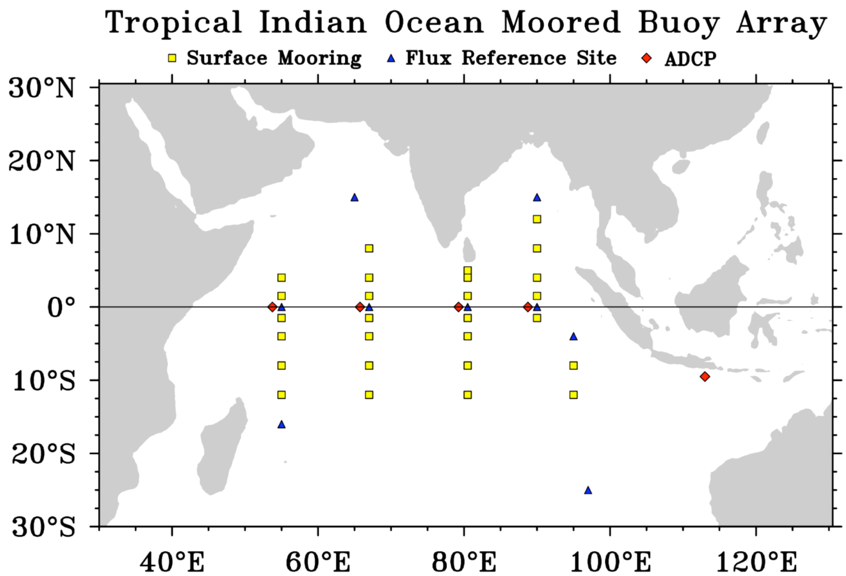


Figure 1. Proposed Indian Ocean Mooring Array.

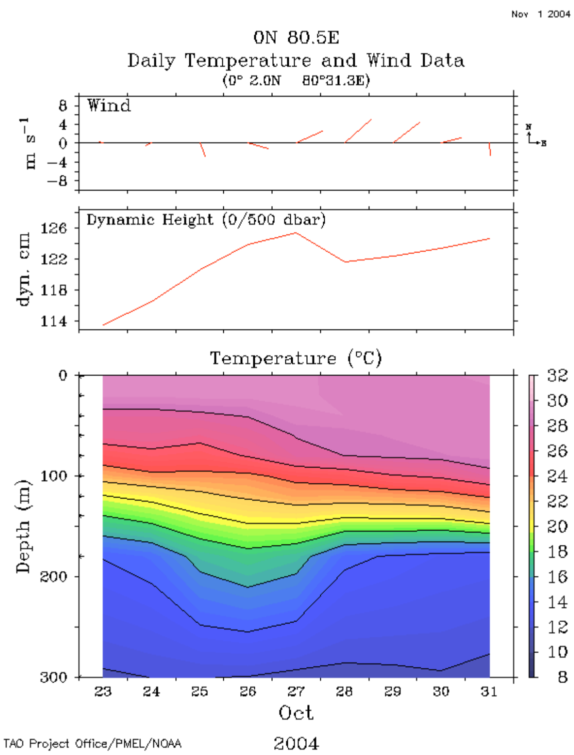
In September we were notified that the cruise ports had been changed, which lead to significant increases in our shipping and travel costs. Customs clearance was delayed for nearly 30 days because problems with the Indian shipping agent and their subcontractor in the new port, resulting in significant additional charges. Finally, in October after PMEL cruise participants had arrived in India, the cruise dates and departure port were again changed, leading to yet more shipping and travel costs. The lesson to be learned from this narrative is that planning and logistics with our Indian colleagues can be highly variable, costly and time consuming. Nonetheless, all equipment arrived in time and the cruise commenced on 11 October 2004.

As of the date of this report (November 1) 3 ATLAS moorings and the subsurface ADCP mooring have been deployed. The ATLAS moorings measure winds, air temperature, relative humidity, precipitation, shortwave radiation, sea surface temperature and salinity, subsurface temperature at 11 depths in the upper 500 m, subsurface salinity at 4 depths in the upper 100 m, ocean pressure at 2 depths, and mixed layer velocity at 10 m depth. The equatorial site is enhanced with additional subsurface temperature, salinity, velocity measurements, plus longwave radiation and barometric pressure to make it compatible with the OceanSITES time series reference station sampling requirements (http://www.oceansites.org). Because of concerns about elevated drag on the moorings due to strong Wyrtki Jets along the equator, the central mooring includes a newly designed load cell with Iridium telemetry.

We prepared and shipped a fourth ATLAS system as a spare in case any problems developed with the 3 primary systems. It was not necessary to use any of the components from this system though and NIO indicated that they did not have space available for storage after the cruise. Rather than ship the mooring back to Seattle, we requested and have received approval to deploy it later on the cruise at 0°, 90ºE. This mooring has the same measurement suite as those as 1.5°N and 1.5°S and will be situated nearby the JAMSTEC ADCP mooring at 0°, 90°E in accordance with the array design in Figure 1.

Real-time data from the ATLAS moorings deployed so far indicate that all systems are working well. Figure 2 shows an example of the initial data from 0°, 80.5°E.

October is a time of transition between the Southwest Monsoon and the Northeast Monsoon when strong westerlies develop along the equator. These westerlies drive an intense eastward current—the Wyrtki jet—in the surface layer. These features are evident in just the first week's worth of data. Also, one can see that as the winds intensified, the thermocline rapidly deepened at the equator, consistent with the notion of local Ekman convergence and downwelling.



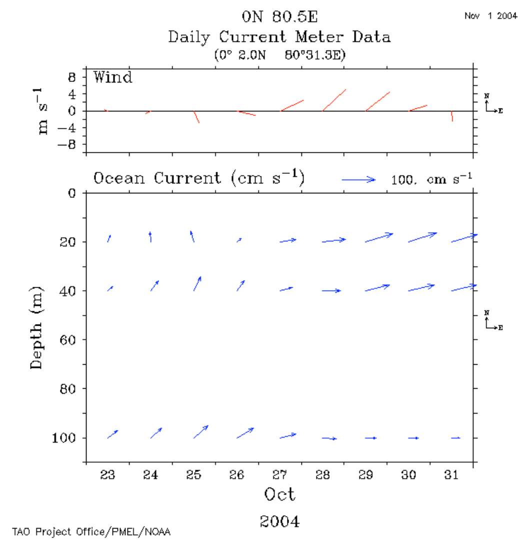


Figure 2. Initial real-time wind, temperature and velocity data from from the ATLAS mooring deployed at 0°, 80.5°E. Note the transition winds and Wyrtki jet in the upper 100m.

In FY 2004 we proposed to develop a 7-element pilot scale ATLAS array over FY 2005-2007 according to the following schedule:

End of FY 2005--3 moorings in the water
End of FY 2006--5 moorings in the water
End of FY 2007--7 moorings in the water

Thanks to the early opportunity provided by this cruise, careful planning, and efficient execution of mooring operations on the cruise itself, we will have 4 ATLAS and 1 ADCP mooring in the water early in FY 2005. Our progress thus far puts us well ahead of our scheduled plans.

3.23a. Pilot Research Moored Array in the Tropical Atlantic (PIRATA)

by M.J. McPhaden

PROJECT SUMMARY

This continuation proposal requests funds to maintain the Pilot Research Moored Array in the Tropical Atlantic (PIRATA) as part of NOAA's effort to “Build a Sustained Ocean Observing System for Climate”. PIRATA is a joint effort between the U.S. (NOAA/PMEL), France (Institut de Recherche Scientifique pour le Développement en Coopération [IRD] and Meteo-France), and Brazil (Instituto Nacional de Pesquisas Espaciais [INPE] which is the Brazilian space agency and Diretoria de Hidrografia e Navegacao [DHN] which is the naval hydrographic service). PIRATA supports NOAA’s strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also underpins Climate Variability and Predictability (CLIVAR) research efforts on tropical Atlantic climate variability. Management of PIRATA is consistent with the "Ten Climate Monitoring Principles". Program oversight at the international level is through the PIRATA Scientific Steering Group and the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A web site containing comprehensive information on the program can be found at http://www.pmel.noaa.gov/pirata/

FY 2004 PROGRESS

Background:

During FY 2004, the PIRATA array was maintained in a 10-mooring configuration as agreed upon for the consolidation phase of the program (2001-2005). Political unrest in the Ivory Coast in the past three years has required shifting of ports-of-call and revision of logistical arrangements for French cruises out of West Africa. The program has proceeded up to the present however without any major interruptions in service.

France and Brazil provide ship time and support for equipment shipments as part of a tri-lateral agreement to maintain the array. PMEL is charged with providing equipment, technical support for moorings and instrumentation, and support for data processing, dissemination, and display. France also provides some technician support.

As in the Pacific TAO array, PIRATA primary variables include winds, air temperature and relative humidity, SST, subsurface ocean temperature and pressure. By design however, PIRATA also includes salinity at the surface and at 3 depths in the upper 120 m, shortwave radiation, and rainfall. Shipboard CTD and ADCP data collection and processing are the responsibility of France and Brazil. PIRATA data are available from the PIRATA web site (http://www.pmel.noaa.gov/pirata/) and the TAO web site (http://www.pmel.noaa.gov/tao/). There are also mirror sites in France and Brazil.

Ship Time and Sea Time:

Ten new ATLAS moorings were deployed on 2 cruises in FY 2004. A total of 39 sea days (21 on the French R/V Atalante and 18 on the Brazilian R/V Antares) were required to service the array. PMEL personnel spent 18 person-days at sea on these cruises, significantly less than in past years. This was mainly because French mooring and electronic technicians are sufficiently familiar with the ATLAS system to deploy and recover moorings without PMEL participation. In addition, PMEL participation on the Brazilian cruise was limited to one technician, with a French technician also aboard. PMEL covered the travel costs of the French technician on the Brazilian cruise.

The Brazilian cruise was only 18 days in duration, but it was split into two legs with six days in port between legs. This cruise schedule significantly increased the travel costs of the PMEL and technician, and caused the French technician to participate in only the first leg.

Data Return:
Real-time data return was 79% overall for FY 2004, 11% higher than for FY 2003. The increased data return was in main due to an improvement in subsurface telemetry hardware. Nevertheless PIRATA data return remains lower than Pacific data return for TAO/TRITON of 86%. The difference between the two basins relates to the greater susceptibility of the smaller PIRATA array to fishing vandalism and to a less frequent servicing schedule (one per year vs. twice per year for much of the Pacific). While no PIRATA moorings were lost in FY 2004, two are presently not transmitting and presumed lost.

Real-time PIRATA data return by variable for FY 2004 (and for comparison, FY 2003) is shown below.

	AIRT	SST	T(Z)	WIND	RH	Rain	SWR	SAL	ALL
FY 2004	92	78	81	68	86	64	84	75	79
FY 2003	83	72	66	73	87	65	84	60	68

PIRATA Web-based Data Distribution:
The TAO Project continues to update the content and functionality of its web site (http://www.pmel.noaa.gov/tao/). This site provides easy access to TAO/TRITON and PIRATA data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. For FY 2004, a total of 2,839 separate user requests delivered 13,559 PIRATA data files. These numbers are up 46% and 8%, respectively from the year before.

Operational Use of PIRATA Data:
PIRATA data are distributed via the GTS to centers such as NCEP, ECMWF, and Meteo-France where they are used for operational weather, climate, and ocean forecasting and analyses. PIRATA data placed on the GTS include spot hourly values of wind speed and direction, air temperature, relative humidity, and sea surface temperature. Daily averaged subsurface temperature data are also transmitted on the GTS. Daily ftp transfers are made from PMEL to the CORIOLIS operational oceanography program in France. The MERCATOR program in France makes use of the CORIOLIS database to generate operational ocean model based data assimilation products. PIRATA data are also available on the GODAE server in Monterrey, California.

The TAO Project Office has been working with Service Argos to include ATLAS salinity data on the GTS. Progress has been made towards this end, with modifications to the GTS subsystem completed and presently being tested.

Vandalism:
Vandalism continues to plague portions of the PIRATA array. Data and equipment return are generally lower in regions of high tuna catch in the Gulf of Guinea, where data return for FY 2004 was about 50% and both moorings in the region are presently not transmitting. Four of the 5 eastern most PIRATA moorings showed evidence of interaction with fishermen (fishing line, missing or damaged sensors, damaged buoys) when recovered in FY 2004.

Efforts to combat vandalism continue, though it is not clear they are making much impact. These efforts include distribution of information brochures to national fishing agencies, fishing boats in ports of call, and industry representatives, and have contributed to international efforts to decrease vandalism through the DBCP. The attractive RM Young wind sensor may be replaced with a less conspicuous sonic anemometer if tests of the latter prove encouraging and funding for system upgrades become available.

TAO Transition Plan:
In a memo dated 13 August 2002, the Deputy Directors for OAR and the National Weather Service

instructed the directors of PMEL and NDBC to develop a plan for transferring PMEL operations to NDBC. The memo was in response to the Administrator of NOAA's endorsement of a recommendation by the NOAA Program Review Team that TAO mooring operations be consolidated with those at NDBC. After several iterations, the Deputy Administrator of NOAA formally approved a TAO transition plan in September 2004.

The NOAA Climate Observing System Council (COSC) reviewed a preliminary version of this plan in which TAO and PIRATA were both proposed for transfer to NDBC. The COSC observed that transfer of PIRATA was premature and recommended against it at this time. That recommendation was incorporated into the final plan. The issue of PIRATA transfer will be reconsidered once a decision is made towards the end of the consolidation phase to continue the program as a permanent component of the Atlantic climate observing system. It is expected that that decision will be made this year.

3.24a. The University of Hawaii Sea Level Center

by Mark Merrifield

PROJECT SUMMARY

The University of Hawaii Sea Level Center (UHSLC) collects, processes, and distributes tide gauge information from around the world in support of various climate research activities. The measurements are used for the evaluation of numerical models (e.g., those in operation at NCEP), joint analyses with satellite altimeter datasets, the calibration of altimeter data, the production of oceanographic products through the WMO/IOC JCOMM Sea Level Program in the Pacific (SLP-Pac) program, and research on interannual to decadal climate fluctuations. Also, in support of satellite altimeter calibration and validation and for absolute sea level rise monitoring, the UHSLC and the Pacific GPS Facility maintain co-located GPS systems at select tide gauge stations (GPS@TG). Over the years the UHSLC has participated in various national and international programs including NORPAX, TOGA and WOCE, and currently is a designated CLIVAR data assembly center and an IOC GLOSS data archive center. Data collected by the UHSLC are managed to meet both the requirements of GLOSS and NCDC's ten climate monitoring principles. The UHSLC distributes in situ sea level directly from its dedicated web site, http://uhslc.soest.hawaii.edu, through a dedicated OPeNDAP server, PMEL's CDP, the NOPP sponsored NVODS project, and the NOSA geospatial and geospatial metadata databases being developed at NGDC. We also are providing in-situ sea level data to the GODAE program. The center also collaborates with NODC to maintain the Joint Archive for Sea Level (JASL), which is a quality assured database of hourly sea level from selected stations from around the world, and continues to work with PMEL on data distribution formats and methods.

The primary UHSLC operations are administered under the Joint Institute for Marine and Atmospheric Research co-operative agreement, and funded by the Office of Global Programs. GPS@TG projects are supported by OGP in the Atlantic Ocean, and by NASA for stations in the Pacific and Indian Oceans. We are working with other groups associated with the global observing system to provide syntheses of various datasets and to compile and distribute associated products.

<u>FY 2004 PROGRESS</u>

Tide Gauge Operations:

The UHSLC operates 39 tide gauge stations in the global sea level network, with 4 in the Global Climate Observing System (GCOS) Category 1 list and 27 in the Category 2 list. In the past fiscal year we serviced 13 sites, installed 3 new stations, and serviced 16 sites remotely. Station maintenance during FY2004 included on-site service trips to Diego Garcia, Settlement Point, Kanton, Baltra, Santa Cruz, Palau, Pohnpei, Manzanillo, Valparaiso, Easter, Male, Gan, Hanimaadhoo. New stations were installed at Christmas Island, Colombo, Sri Lanka and Salvador, Brazil. Stations that developed problems that our technicians were able to solve remotely during FY2004 included Point La Rue, Port Louis, Hululue, Azores, Lamu, Easter, Salalah, Settlement Point, Baltra, Saipan, Tern Island, Rikitea, Penhryn, Yap, Ushuaia, Manzanillo, and Diego Garcia. We are upgrading key network sites to acoustic or radar sensors in place of the older float gauges, and an on-site data storage device has also been in development as a back-up system when satellite transmissions fail. The historical data return for the UHSLC network is 93.8%, the current year's return is 95.3%, and the previous years return 96.8%.

The UHSLC is providing technical support to the ODINAFRICA project, which will oversee the installment of 10-20 new tide gauges in Africa. The center is working with the Survey of India (SOI) on a plan to install satellite transmitting gauges at selected Indian GLOSS and GCOS sites, and to produce a quality assured database of hourly sea level from selected Indian stations. A MOU between NOAA and BAKOSURTANAL in Indonesia has been drafted for the purpose of upgrading the Indonesian tide gauge network. The UHSLC will help install up to 6 new gauges in the region, and contribute ongoing technical and scientific support for the operation of the network.

We have completed 7 GPS installations to date, and we are continuing to explore opportunities for further expansion in this area. We are negotiating with the Azores about a possible installation. The center is also in contact with the National Tidal Centre (NTC) in Australia concerning their South Pacific gauges, and with agencies in Brazil.

Dataset Holdings:
The Joint Archive for Sea Level (data latency: 1-2 years) is a collaborative arrangement between NODC, the World Data Center-A for Oceanography, and the UHSLC. Beginning in the fall of 2000, the JASL was supported by NOAA's NCDDC. The JASL produces a quality assured database of hourly sea level from stations around the world. In the past year, the UHSLC increased its JASL holdings to 10,007 station-years, including 5617 station-years at 202 GLOSS sites. Of the 101 GLOSS stations that are presently operating on islands, 93 are available through the JASL. The 2003 submission of the JASL data to the World Data Center-A for Oceanography included 120 series that contained measurements through the year 2002. We are also working with IPRC to ensure that the JASL delayed mode observations are available through the APDRC servers.

The UHSLC maintains a fast delivery database (data latency: 1 month) in support of various national and international programs (e.g., GODAE, CLIVAR, GLOSS, GCOS). To ensure active participation and coordination with the international community, the database has been designated by the IOC as a component of the GLOSS program. The fast delivery data are used extensively by the altimeter community for ongoing assessment and calibration of satellite altimeter datasets. In particular, fast delivery data are used for monitoring the latest JASON altimeter and for the tie between JASON, TOPEX/Poseidon, ERS, and GEOSAT satellites. The fast delivery sea level dataset now includes 141 stations 113 of which are located at GLOSS sites, of which 44 are located at GCOS 1 sites, and 43 at GCOS 2 sites. The historical return for the fast delivery dataset is 94.0%, the current year's return is 94.8%, and the previous year's return 95.5%.

We are working with the GODAE steering committee to ensure that tide gauge information in real-time is available through the UHSLC. Approximately 70 stations currently are available on this time frame with plans for ongoing expansion. When operational, we will distribute this product through our web site, and make it available in a netCDF format via an OPeNDAP (formerly DODS) server.

As part of the JCOMM SLP-Pac, the UHSLC operates a Specialized Oceanographic Center that produces sea surface topography maps (monthly) and diagnostic time series (quarterly) for the Pacific Ocean. This activity is a continuation of one of the earliest examples of operational oceanography. The UHSLC presently distributes these products through the Internet and by mail to users. The net result is that approximately five weeks after the end of a month, hundreds of users throughout the world receive an analysis of the state of the Pacific Ocean sea surface topography for that month. The analysis includes comparisons of tide gauge and altimeter sea surface elevations that are available through the UHSLC web site.

The UHSLC distributes in situ sea level and associated products directly from dedicated web and anomalous ftp sites. Both have been designed such that the response is very fast. The code has been kept very simple and focused on the tasks that the users will want. Whether the user has access via a dial-up modem, cable, or DSL the access speed is kept high by using small, compressed, pre-generated images sent from a central server. This allows users worldwide to conveniently acquire the center's holdings. The center produced cdroms that mirror the UHSLC web site. These cds are distributed with the JASL annual data report, shared with all data originators, and sent to other users upon request. Over 100 were distributed again last year.

Research Highlights:
Interannual and decadal changes and sea level rise have been our primary research focus areas during FY2004. A manuscript describing decadal oscillations in sea level in the eastern Pacific is in press at the Journal of Physical Oceanography. We have described how the long sea level record collected at the Honolulu tide gauge is connected to Pacific North America (PNA) related fluctuations in winds and surface pressure.

We are continuing our study, in collaboration with the NTC, of a case history of sea level data collection at the Funafuti atoll in Tuvalu. The UHSLC maintained a station at Funafuti for nearly 20 years. The data are now being extended forward by the NTC. This paper will document how a consistent high quality time series that is useful for climate studies is collected and managed.

The island of Hawaii experienced one of the highest sea level events on record during the latter part of 2003. Flooding of low-lying coastal areas and enhanced beach erosion throughout the State were attributed to this event. A paper describing the role that mesoscale eddies play in these events is in review at Geophysical Research Letters. Similar extreme event analyses are planned for other island regions.

A study of island sinking rates along the Hawaiian island chain formed the basis for a student Masters thesis and an article submitted that is currently in review at Geophysical Research Letters. Differences in sea level rise rates recorded at Hilo and Honolulu have long been attributed to variable subsidence rates associated with volcanic activity. Continuous GPS measurements indicate that the rates are more similar between the islands. We find that recent sea level rate differences are due in part to steric variations associated with large-scale wind patterns. We are extending this analysis to consider differential GPS rates at tide gauges throughout the Pacific.

Estimates of coastal sea level rise in the Southern California region are being made in conjunction with Ben Brooks at the Pacific GPS Facility. SAR images are used to estimate vertical ground motion along the entire coastal strip. Tide gauge and GPS information are then incorporated to give a full description of relative sea level variability along the coastline.

We are collaborating with Philip Woodworth of the Proudman Oceanographic Laboratory and Gary Mitchum of the University of South Florida on an annual report describing sea level variability for the previous year (similar to the climate assessments made each year in the Bulletin of American Meteorological Society). The first set of products is under development, including updates on sea level trends, extreme events, and large-scale variations.

Our research effort has advanced our understanding the GPS ground motion datasets at each of our sites, with the goal of providing absolute sea level trends at all GPS@TG stations. We are working with Mike Bevis of Ohio State University to establish a global reference frame in which to analyze the GPS vertical data. In conjunction with the GPS analysis, we are making a thorough evaluation of all benchmark survey datasets at UHSLC sites. This work could be accelerated with more resources (see add task 2).

The JASL and CLIVAR/GLOSS datasets were added to the NOSA geospatial and geospatial metadata databases being developed at NGDC. These databases are expected to play an important role in the NOAA Enterprise GIS efforts. This arrangement allows the UHSLC datasets to be accessed along with other NOAA supported climate products through the NOSA web site. The center continues to work with the ncBrowse and Climate Data Portal projects. The center's goal is to integrate all of our datasets and products into these systems. We have continued to integrate the UHSLC datasets and products into the NVODS LAS.

Figure 1. Tide gauge data collected by the UHSLC with data latency (time from observation to distribution) indicated in color.

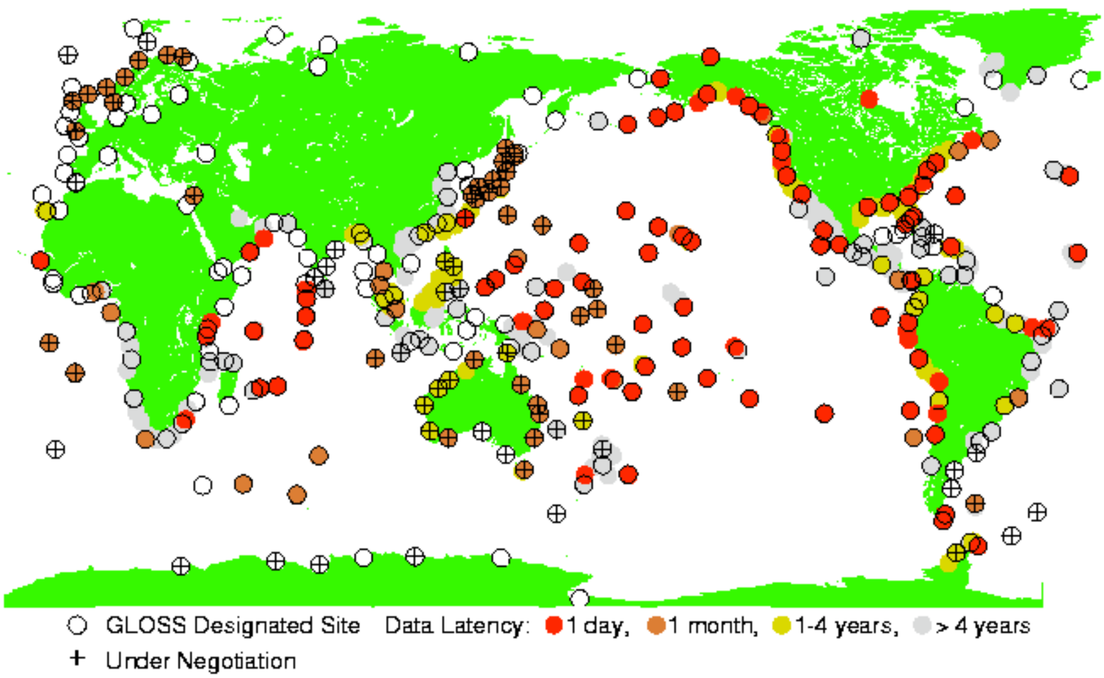
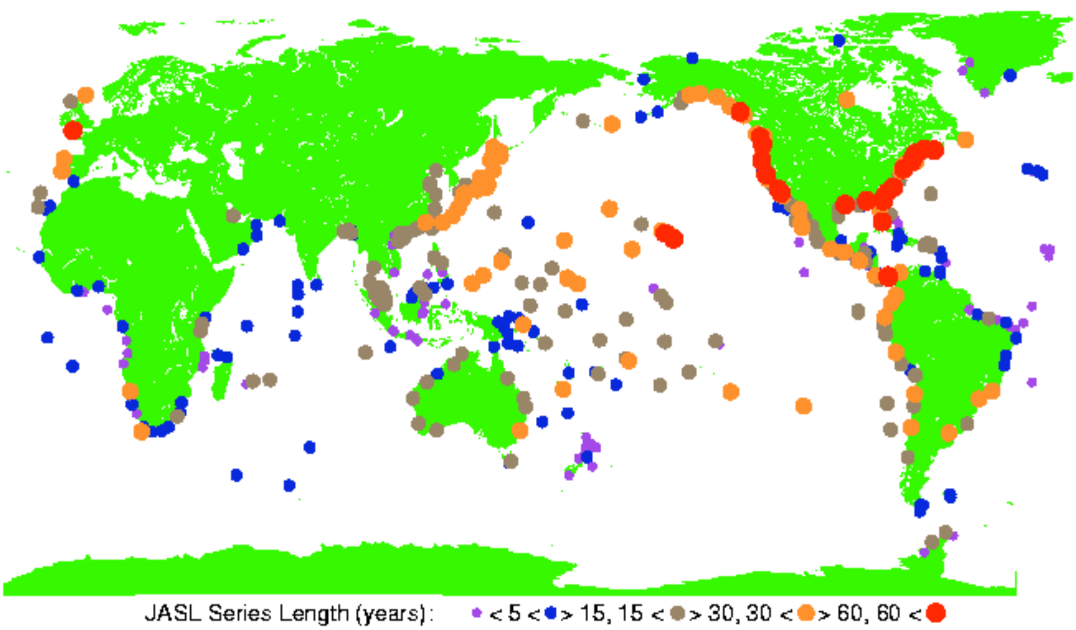


Figure 2. Sea level time series record lengths in the Joint Archive for Sea Level (JASL).



3.25a. Satellite Altimetry

Laury Miller

PROJECT SUMMARY

Satellite altimetry is a unique type of ocean remote sensing observation because it provides much more than a surface measurement. Spatial and temporal variations in sea surface height are driven by temperature and salinity changes throughout the water column. The NOAA Laboratory for Satellite Altimetry (LSA) has been involved in every satellite altimeter mission: Geos-3, Seasat, Geosat, ERS-1, Topex/Poseidon (T/P), ERS-2, Geosat Follow-On (GFO), Jason-1, and Envisat. Many of these have been research programs or operational demonstrations. However, since the mid-1990s it has been possible to produce quick-look, altimeter-generated analyses of sea surface height with sufficient accuracy and resolution to have operational utility. This capability is largely due to advanced satellite orbit determination techniques based on systems like the Global Positioning System. As a result, NOAA now incorporates satellite altimetry in a number of its operational products. For example, near-real time sea surface height analyses are assimilated into NCEP ocean models used to forecast El Niño, hurricane intensification, and coastal circulation. Over longer time scales, altimetry is being used to observe the North Atlantic Oscillation and monitor global sea level rise.

Because of the value of altimetry to NOAA and the U.S. Navy, a commitment has been made to fly altimeters operationally as part of the National Polar-Orbiting Operational Satellite System (NPOESS) beginning in 2013. In the meantime, NOAA must continue to leverage its resources to take advantage of existing satellite altimeter missions, and prepare to assume responsibility for the Jason-2 ground system beginning in 2008.

This project contributes to the NOAA goals (1) Understand climate variability, and (2) Serve society's needs for weather and water information. It provides the satellite altimeter "research-to-operations" component of NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate.

LSA maintains connections with many agencies, institutions, and programs. LSA staff members serve on NASA's Ocean Surface Topography Science Team, the Envisat altimeter advisory group, and science teams for CryoSat, and IceSat. See http://ibis.grdl.noaa.gov/SAT/.

FY 2004 PROGRESS

Four altimeters were operating during 2004: GFO, T/P, Envisat, and Jason-1. Most of the Climate Observations altimeter funds were used to support GFO, which is a NOAA-Navy collaboration.

(a) GFO

Geosat Follow-On (GFO) has been operational since 2000. During 2004, LSA provided partial funding for the precise orbit determination effort and also supports a calibration/validation team at Ohio State University. LSA worked closely with the Navy, NASA, universities, and project contractors to prepare and distribute the final, research-quality Geophysical Data Records (GDRs). Thus far, LSA has produced 4 years of GDRs and distributed the data to users on DVD (http://ibis.grdl.noaa.gov/SAT/gfo/). GDR production and distribution will continue routinely for the life of the GFO mission. It is estimated that the satellite will operate until at least 2006. In addition to the research data sets, GFO is a source of near-real time sea surface height that is used by the Navy and NOAA for ocean and atmosphere operations. As an example, the National Hurricane Center uses all available altimetry to compute "hurricane heat potential" maps as an aid to forecasting storm intensification, and GFO contributes significantly to the analysis.

(b) Geosat

The Geosat mission (1985-89) provided the first long time-series of altimetry measurements and allows us to extend multi-mission altimetry back 7 years prior to T/P. LSA has completed a data recovery project for the Geodetic Mission data (GM, 1985-86) and needs to secure funding to recover the remaining Exact Repeat Mission data. This requires a data forensics firm equipped to transfer the original Sensor Data Records (SDRs) from aging 9-track tapes to modern media. The cost is estimated to be in the $100-200K range. The GM data are particularly useful for geophysical applications such as predicted bathymetry. By merging the SDRs with the original altimeter waveforms (obtained from a separate archive at NASA Goddard) we have been able to significantly improve the along track spatial resolution. Refinements in the re-tracking of the waveforms will ultimately provide a much sharper picture of the small-scale seafloor structure and marine gravity field. To further improve the Geosat data, a new orbit will be computed that leverages the tuned gravity model of GFO, which flies in the same 17-day repeat orbit as Geosat. Global sea-level rise studies will benefit from the extra 7 years of data from an improved Geosat time-series.

(c) T/P and Jason-1

The 10-year archive of T/P sea level analyses was kept up to date on the LSA web site, together with the Pacific island tide gauge comparisons that have become the standard for monitoring the health and accuracy of the T/P observations. Jason-1 has now replaced T/P as the high-precision satellite altimeter, and NCEP is receiving analyses operationally for applications such as El Nino monitoring and coastal current forecasting.

The LSA is supporting a study by a student of Dr Steve Nerem, University of Colorado, to improve estimates of Global Sea Level Rise (GSLR) over the past 50 years using a combination of satellite altimeter and tide gauge observations. The work involves applying regional spatial patterns of sea level rise determined from 13 years of T/P and Jason-1 altimeter data to longer but more sparsely sampled tide gauge records. As part of the collaborative aspect of this project, the student, Tom Jakob, spent last summer working with Laury Miller at the LSA.

(d) Jason-2

LSA spent a significant amount of time planning for NOAA's new role in Jason-2. Jason-2 will be a 4-agency partnership with contributions from NOAA, NASA, CNES, and EUMETSAT. A new Jason-2 initiative for FY06 was approved by DOC in August 2004. This would provide $1.6 M to allow NESDIS to assume responsibility for command/control from Suitland, downlinks at Wallops and Fairbanks, operational processing and distribution, and archive.

(e) Global Sea Level Rise

The rate of 20th century Global Sea Level Rise (GSLR) and its causes are the subjects of intense controversy. Most in-situ measurements from tide gauges made over the past 50 to 100 give a rate of about 2 mm/year, while indirect estimates based on the two processes responsible for sea level rise, namely mass and volume change, fall far below this figure. Estimates of the volume increase due to ocean warming produce a rate of about 0.5 mm/year and the rise due to mass increase, primarily from the melting of continental ice, is thought to be even smaller. To further complicate matters, estimates of GSLR based on measurements made by T/P, Jason-1 and four other satellite altimeter missions over the past decade indicate a rate of about 3 mm/year. In a recent paper, Miller and Douglas (*Nature*, 2004) resolved some of this controversy by demonstrating that tide gauge estimates of GSLR are not biased high, as some have suggested due to coastal warming, and that the rate due to mass increase is actually 2 to 3 times greater than the rate due to volume increase. In short, they found that 2 mm/year is a reasonable figure for the 20th century rate of GSLR. The question of how this result relates to satellite altimeter estimates of the past decade is topic of a joint research project with Dr. Steve Nerem, University of Colorado, (see section c.)

3.26a. The Global Drifter Program:
Global Drifter Measurements of Surface Velocity, SST and Atmospheric Pressure
by Peter Niiler

PROJECT SUMMARY

Rationale: The principal scientific questions of the role of the ocean in climate change are how well can we describe or model the ocean circulation today and how well can these descriptions or models predict the evolution of future climates. Drifters provide the instrumental data sets for describing ocean surface circulation and SST evolution and these data are used for testing climate models. Atmospheric pressure is assimilated into weather prediction models and is used by operational meteorological agencies to discern severe weather conditions over the oceans.

Objectives of the Global Drifter Program:

The "Global Drifter Program" (*GDP*) is the principal international component of the *"Global Surface Drifting Buoy Array"*. It is a scientific Project of the DBCP of WMO/IOC. It is a near-operational ocean-observing network of drifters that, through the ARGOS satellite system, returns data on ocean near-surface currents, SST and atmospheric pressure (and winds and salinity) and provides a data processing system for scientific utilization of these data. In addition to *GDP*, drifters are deployed by operational oceanographic and meteorological agencies, whose data are utilized by *GDP*. In turn, *GDP* data are made available on GTS to operational users. Barometers, wind-sensors and salinity sensors can be and are added to SVP drifters. The international protocols for these data exchanges and sensor additions are worked out each year by DBCP.

The scientific objectives of the *GDP*, and its operational partners, are to:

1) Provide to GTS an operational, near-real time data stream of SST, sea level pressure (and surface velocity).
2) Observe the mixed layer velocity on a global basis with 0.5° resolution and produce new charts on the seasonal and interannual changing circulation of the world ocean (Fig. 1).
3) Develop and introduce into the drifter construction technological advances in sensors, electronics, power, methods of assembly and deployment packaging.
4) Provide enhanced research quality data sets of ocean circulation that include drifter data from individual research programs, historical data from instruments different from the Surface Velocity Program (SVP) Lagrangian Drifter and the corrected data sets for wind-produced slip of drifter velocity.

GDP:

- Provides to the coupled ocean-atmosphere climate modelers gridded, global data sets of SST and near surface circulation and dynamic topography and for assimilation and the verification of the parametrized processes, such as wind-driven Ekman currents.
- Provides the Lagrangian data sets for the computation of single particle diffusivity, dispersal of ocean pollutants, the enhancement of models of fisheries recruitment and improvement of air-sea rescue.
- Obtains high-resolution coverage of ocean variability and time mean circulation in support of ENSO prediction model verification in the tropical Oceans and supports short-term research projects that require enhanced upper ocean velocity observations.

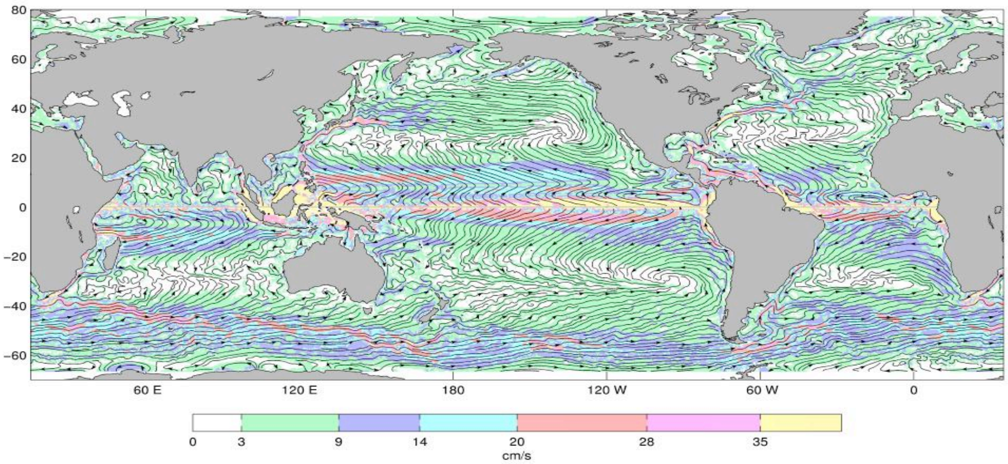


Figure 1. The streamlines of 1992-2003 15m-depth drifter derived currents at 0.5º resolution (Courtesy of N. Maximenko, U. of Hawaii, IPRC, 2004). This figure reflects the mean near surface circulation of the global ocean.

Required Drifter Observations and Status of Global Array:

GDP began in 1988 as a TOGA research program. WOCE made contributions in the period 1991-1993. Between 1992 and 2003, an array of 600 SVP drifters was maintained in the global ocean with contributions of resources from a variety of operational and individual research programs. Since October 2003 the array has consisted of over 900 drifters. Full implementation for SST observations will be completed by June 2005.

The 'required' global drifter array size is based on the need to maintain 1250 platforms that return instrumental observations of daily average SST (+/- 0.1^0C) over the global ocean at the 5º resolution, or the spatial scale of the error covariance function of satellite SST sensors. Surface pressure sensors are also supported by regional meteorological agencies based on local needs.

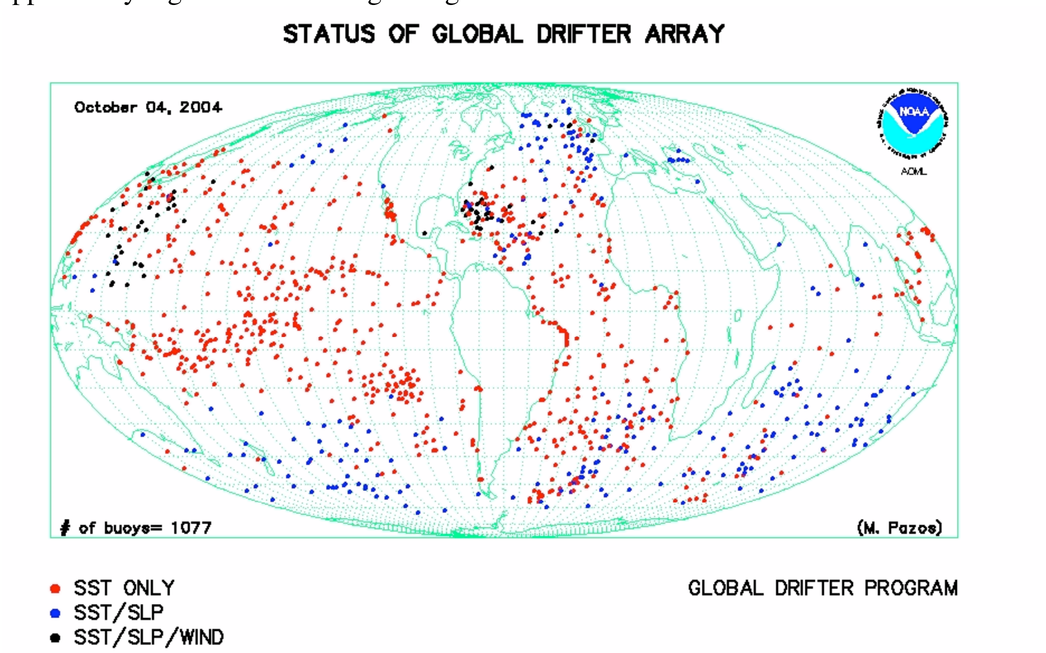


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Figure 2. The Global Drifter Program array on October 4, 2004.

The actual number of drifters in the array will be larger than 1250 because the required uniform spatial distribution will be difficult to maintain in the complex ocean surface circulation and many drifters go ashore in remote locations. On October 4, 2004 1077 of the 1250 ‘required drifters are reporting to GTS and the AOML *Drifter Data Center* (Figure 2). NOAA Climate Observation Program, together with cooperation of ONR, has funded sufficient numbers of SVP drifters (940) in FY’04, and with the expected contributions of drifters (200-300) from other sources, the array will be fully deployed by June 2005. In 2005 will begin more directed efforts to adjust the array spatial density.

Management:
GDP reports every year to the DBCP, for advances in technology in the Technical Sessions and in deployment plans and organization in the Plenary Sessions. *GDP* is largely a NOAA funded program and is managed according to the *“Ten Climate Monitoring Principles”* established by JCOMM. In these tasks, there is close coordination between the following entities:

• US manufacturers in private industry (*Technocean, Inc*. of Cape Coral, FL*; Clearwater, Inc*. of Watertown, MA*; Pacific Gyre, Inc*. of Carlsbad, CA*)* who build the SVP drifters according to closely monitored specifications. Internationally a total of 6 private firms and 3 research laboratories build SVP drifters.

• Atlantic Oceanographic and Meteorological Laboratory (AOML) who carries out the deployments at sea, processes the data and archives these at MEDS, Canada, maintains the META file on the description of each drifter deployed, and the upgrades the *GDP* website,

• Joint Institute of Marine Observations at the Scripps Institution of Oceanography (JIMO/SIO) who supervises the US industry, acquires the NOAA funded drifters, upgrades the technology, develops sensors and enhanced data sets and maintains liaison with individual research programs that deploy SVP drifters. Periodically, drifter construction manuals are upgraded and are posted on the DBCP website.

The requirements of the international science bodies from the drifter array are to provide instrumental observations of SST. In the research community 99% of reviewed scientific research papers use drifter velocity observations: (viz. list of publications at:
http://www.aoml.noaa.gov/phod/dac/drifter_bibliography.html)
Nearly all research program contributions to the drifter array have been justified on the basis of upper ocean velocity observations.

FY 2004 PROGRESS
Funding of the FY’04 Global Drifter Program, and the ancillary CORC and ONR sponsored activities at JIMO/SIO, occurred in the last week of September 2004. Since then the following activities have taken place, jointly with CORC funding:

1. *Drifter Acquisitions and Technology: In summary, 967 drifters and 8 temperature chain wind drifters were ordered and 60% will be delivered in time for deployment before June 2005.*

   a) A total of 550 SVP-Mini drifters were ordered from Clearwater Instruments, Inc and Technocean, Inc. These will be delivered to AOML for deployment. Component parts for an additional 210 SVP-Mini drifters were ordered (jointly with ONR funds) from Clearwater Instruments, Inc and Pacific Gyre, Inc. These component parts will be sent to Busan National University for assembly and deployment in to the western Pacific in support of CORC and ONR joint sponsored activities.
   b) A total of 125 SVP-B drifters were ordered from Technocean, Inc. and Pacific Gyre, Inc. These will be deployed under the direction of AOML in the North Pacific (50) and the Southern Ocean (75).

c) A total of 12 Minimet wind-drifters were ordered from Pacific Gyre, Inc. These will be configured for air-deployment into the Atlantic hurricane(s?) during the 2005 season.
d) Components for a total of 20 SVP-Sea Surface Salinity (SSS) drifters were ordered from Seabird, Inc. and Pacific Gyre, Inc. These will be assembled at SIO; 12 will be sent for deployment into the North Atlantic by MeteoFrance in March 2005 and they will make a best effort will for recovery and recalibration over the following 12 month period; 8 will be sent for deployment into the East China Sea to study the effects of the construction of the Great Yangtze River Dam.

3.27a. Climate Variability in Ocean Surface Turbulent Fluxes

by James J. O'Brien, Mark A. Bourassa, and Shawn R. Smith

PROJECT SUMMARY

Ocean surface turbulent fluxes will be examined for climate-related variability. Typically SSTs, winds, and pressures are examined in such studies. The observed changes in winds (speed and direction) and SSTs alter turbulent surface fluxes, which have a far-reaching influence on regional climatologies. It is expected that surface turbulent fluxes (stress, sensible heat, and latent heat) are more directly linked to climate-related changes than winds and pressures. Similar approaches will be applied to two overlapping periods. We are objectively deriving a high quality set of monthly surface fluxes (and related fields), covering 1950 to 2005, for the global oceans north of ~30°S to examine variability on a wide range of spatial and temporal scales (seasonal to decadal). Similar daily fields (including surface radiative fluxes) are under development from July 22, 1999 through 2005, with greater spatial resolution. Our goal is to produce the most accurate flux fields available.

Reanalysis surface fields have large biases and systematic errors in comparison to surface truth (Cotton et al. 1999, Renfrew et al. 2000, Smith et al. 2001). The physics of the boundary layer are not well modeled in NWP reanalyses, resulting in poor surface fields. The errors are sufficiently large to bias climate-related studies (Cotton et al. 1999, Smith et al. 2001); therefore, in-situ (ship and buoy) observations are being objectively combined to create a better turbulent-flux product. Comparing subjectively-derived, in-situ based, Equatorial Pacific surface wind products (the FSU winds) to the NCEP/NCAR Reanalysis clearly verified the above mentioned shortcomings (Putman et al. 2000). However, the FSU wind fields are excellent matches to satellite ocean surface vector wind fields (Pegion et al. 2000), thereby confirming the accuracy of the in-situ based products. The surface flux fields developed though this study can be used to help validate flux fields created with couple ocean-atmospheric models (after the removal of the above short comings). The techniques developed in this study will also be of use for programs such as GODAE and SEAFLUX (which require the assimilation of data from multiple platforms), as well as energy budget studies based on WOCE and GOOS observations. The flux analysis methods will also be of interest to the newly formed WCRP working group on surface fluxes.

An objective analysis technique (Bourassa et al. 2004) has been developed to produce fields of surface turbulent fluxes (momentum, latent heat, and sensible heat fluxes) and the fields used to create the fluxes (vector wind, scalar wind, near-surface air temperature and humidity, SST, and pressure). This approach treats the various types of observations (volunteer observing ships, moored buoys, drifting buoys, different satellites) as independent, and objectively determines weights for each type of observation. The weights for each type of observation are objectively determined.

The flux project at FSU targets the data assimilation milestones within the Program Plan. Our assimilation efforts combine ocean surface data from multiple Ocean Observing System networks (e.g., VOS, moored and drifting buoys, and satellites). One set of performance measures targeted in the Program Plan is the air-sea exchange of heat, momentum, and fresh water. When products are combined with ocean models (either at FSU or other institutes), performance measures relating to surface circulation and ocean transports can be addressed. The FSU flux project also focuses on the task of evaluating operational assimilation systems (e.g., NCEP and ECMWF reanalyses) and continues to provide timely data products that are used for a wide range of ENSO forecast systems.

All development of the objective flux system and operational production of the FSU winds and fluxes are the responsibility of COAPS. Our satellite partners include Gary Wick (NOAA-ETL; satellite SST), Frank Wentz and Deborah Smith (Remote Sensing Systems; scatterometer winds, passive microwave scalar winds, passive microwave SST), and Bill Rossow and Yuanchong Zhang (NASA; radiative fluxes). We maintain a long-term collaboration with Dr. Jacques Servain (IRD, France) who focuses on data and products for the tropical Atlantic Ocean. We also continue to collaborate with U. S. and international partners in the CLIVAR program, SEAFLUX, and GODAE to provide the wind and flux products needed to achieve these projects goals. All the FSU wind (and eventually flux) products are freely available at: http://www.coaps.fsu.edu/RVSMDC/SAC/.

The FSU flux project began managing its operation in accordance with many of the Ten Climate Monitoring Principles long before they were spelled out by the NRC. We continue to fully document and provide free access to all of the FSU wind and flux products. The FSU Pacific and Indian Ocean winds have been continuously produced and distributed since the mid-1970s, and a historical retrospective containing past procedures and methods in now published (Smith et al. 2004). We endeavor to maintain a consistent product over many years and are careful to include parallel testing whenever possible before changing analysis methods. When a former product is discontinued, we provide a comparative assessment of the new and old products to aid the users transition (e.g., Bourassa et al. 2004). Finally, we continually evolve our data access and distribution system to take advantage of new distribution formats (e.g., netCDF) and access technology (e.g., LAS, DODS). This evolution will continue in the future to achieve the goals of new data management programs (e.g., Ocean.US IOOS-DMAC).

FY 2004 PROGRESS

In-situ surface wind and flux products

The objective method (Bourassa et al. 2004) continues to be applied to create two-degree tropical Pacific Ocean wind (pseudo-stress) fields based on in-situ data input. Quick-look two-degree gridded pseudo-stress fields are produced at the beginning of each month using the previous month's GTS-transmitted data, and a research product for the preceding year is produced each summer using delayed-mode GTS data from NCDC. In addition, COAPS continues to produce one-degree pseudo-stress fields for the tropical Indian Ocean using the method of Legler et al. (1989). A switch to produce Indian Ocean fields with the Bourassa et al. (2004) method was delayed due to the complicated nature of developing a new one-degree objective system (see below). Both two-degree fields for the Pacific Ocean and one-degree fields for the Indian Ocean FSU winds are available at
http://www.coaps.fsu.edu/RVSMDC/SAC/index.shtml. Objective Pacific winds (known as the FSU2) are available for 1978-2003 (research) and Jan. - Sept. 2004 (quick-looks). Indian Ocean winds are available for 1970-2003 (research) and Jan. - Sept. 2004 (quick-looks).

The 2°x2° FSU2 and the subjective FSU product for the Equatorial Pacific Ocean have been compared to monthly averages of scatterometer (NSCAT and QSCAT) pseudostress analyzed on the same grid as the FSU2 winds. The scatterometer observations are gridded with the same objective technique used herein, except that the satellite uncertainty estimates consider observational error and representativeness, there is no manual quality control of the scatterometer data, and the length scale for spatial smoothing is approximately one tenth of the scale for in situ data. The scatterometer observation density is sufficient to produce much finer spatial resolution for monthly time scales: scatterometer winds are the best available standard of comparison. The comparison times are Oct. 1996 through June 1997 for NSCAT, and Aug. 1999 through Dec. 2003 for QSCAT. The comparison to scatterometer data includes mean differences (biases) as well as standard deviations, which are more indicative of seemingly random differences.

The comparisons of mean differences (Fig. 1) between the scatterometer and FSU wind products have similar spatial patterns, however, the differences between the scatterometer and subjective FSU pseudostress are much greater than for the objective (FSU2) pseudostress. The clearest pattern occurs in the meridional wind comparisons and is related to an underestimation of the FSU products’ convergence about the ITCZ. The zonal differences are partially due to the scatterometer measuring current relative winds while the in situ winds are earth relative. The magnitude and direction of speed biases (Fig. 1, top) near the equator are consistent with the South Equatorial Current (SEC; Kelly et al. 2001). The biases near the SEC are also partially due to the broad spatial smoothing used to create the background field for the FSU2. The speed biases to the North of the North Equatorial Counter Current (7° or 8°N) are greater than the observed and modeled currents. This region has very sparse coverage, and the information that propagates into this region is a relatively poor match to local conditions. For a strong majority of locations, the magnitude of the bias in stress components is <0.006 Nm^{-2}.

Greater differences between the subjective and objective FSU winds are seen in standard deviations of differences with scatterometer winds (Fig. 2). These standard deviations are much greater in the comparisons with the subjective FSU winds. The subjective FSU product has local maximums around the ITCZ and the SPCZ. The subjective products shortcomings related to the SPCZ are likely due to the use of 10° longitudinal bins in the hand analysis. The FSU2 also has remarkably improved accuracy in the western Pacific Ocean. Presumably the good quality of the FSU2 winds extends as far back as there are adequate in situ observations. Degradation in quality with time can be examined in future studies if in situ data from the scatterometer time period can be sub-sampled to simulate coverage during earlier times.

Development of a high quality 1°x1° in situ based product (which was requested by users of our products) has proven to be much more complicated than expected. We have overcome or are near overcoming these problems:

1) Differences between the uncertainty of moored and drifting buoy winds,
2) For finer spatial/temporal resolution products, sampling-related differences in observing systems are more apparent,
3) Near coastal features must be much more finely resolved,
4) For the Pacific basin, working with 1°x1° binned data results in too much data to be manually quality controlled.

The first three problems were particularly evident near coastlines, in archipelagos, and near TAO buoys. These problems have been resolved through five modifications to our approach. For example we now treat moored and drifting buoys as separate types of platforms. Our solution to the fourth problem (based on quality assurance techniques developed in our quality control of research ship data) is undergoing testing. This approach is expected to save a great deal to time, particularly for flux products.

<u>Satellite surface wind and flux products</u>

Development of our satellite-based products continues. We can now produce fields on an arbitrarily fine spatial resolution. We take advantage of this utility when examining fine structure, usually within observational swaths. Currently, we are using such fields to examine the transition of tropical cyclones to extratropical cyclones. We have also nearly completed work on the uncertainty of the wind fields. For global gridded fields the uncertainty is dominated by sampling issues. It is only for fine spatial resolution, high temporal resolution fields within swaths that the observational uncertainty dominates the uncertainty in the gridded output.

Currently available products are:

- Daily average pseudostress fields:
  http://www.coaps.fsu.edu/scatterometry/Qscat/gcv_glob_L2B_1x1.html
- Monthly global 1x1 fields:
  http://www.coaps.fsu.edu/scatterometry/Qscat/gcv_glob_L2B_1x1_mon.html
- 12-hourly fields for the Gulf of Mexico
  http://www.coaps.fsu.edu/scatterometry/Qscat/gcv_glob_L2B_hlfxhlf_GofM.html
- Monthly global 0.5x0.5 pseudostress fields
  http://www.coaps.fsu.edu/scatterometry/Qscat/gcv_glob_L2B_hlfxhlf.html

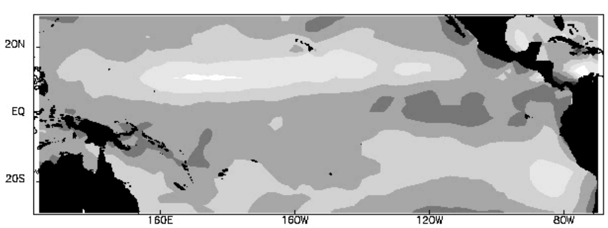
We have used our gridded surface winds to examine the propagation of the Madden-Julian Oscillation (MJO). The MJO causes very important variability in the tropics, and is usually identified by its signal in outgoing long wave radiation and in cloud cover. We have shown that there is a very strong signal in the surface winds (Arguez et al. 2004).

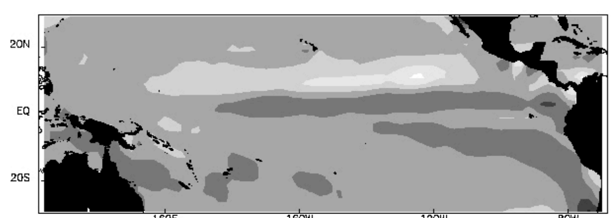
The gridded satellite wind fields have been used to examine variability in the southern ITCZ (SITCZ) in the eastern Pacific Ocean. The results show that our gridded fields are capturing the expected variability on scales of approximately 5 days. Averaging on a monthly scale, such as is necessary with the in situ data alone, hides the vast majority of this variability as the existence of the SITCZ. The advection of divergence from the north is caused by several considerations: large scale increase in southward winds associated with gap flow, and spatial changes in vertical mixing associated with changes of atmospheric stability on these spatial scales (Jones 2004).

We are now coupling scatterometer wind observations with various NWP fields to construct forcing fields for our Gulf of Mexico ocean model. This atmospheric forcing is coupled with ocean model through surface turbulent fluxes calculated with an updated version (Bourassa 2004a,b) of the Bourassa-Vincent-Wood flux model (Bourassa et al. 1999). The new water-wave related physics considered in this model results in more accurate surface turbulent fluxes for wind speeds from 2 to 30 ms^{-1}.

We have solved a problem related to temporally inconsistent data used for sea surface temperature (SST) and air temperature. For example, weekly Reynolds SSTs combined with NWP air temperatures. In too many cases this combination resulted in a net transfer of atmospheric water vapor to the ocean. We have solved this problem by changing the form of moisture used in the objective method from specific humidity to relative humidity. This approach has removed the possibility of super-saturation of the atmosphere near the ocean surface, resulting in much more realistic moisture fluxes.
Prototype SST fields are currently being constructed from microwave SST products. Traditionally, SST fields are either constructed for a week, or based only on pre-dawn observations. These options avoid complications due to the diurnal cycle. We are considering a new approach that would consider the diurnal cycle and would utilize all the observations. This approach should result in more accurate fields and allow for a much finer resolution of the diurnal cycle.

As noted earlier, the FSU2 winds are being freely distributed via the web. The data are also available via anonymous ftp (ftp coaps.fsu.edu/pub/wind) and the DODS (http://www.coaps.fsu.edu/RVSMDC/html/dods.shtml). We are currently working to install a LAS. The operational Pacific FSU2 pseudostress fields continue to be used by U. S. government agencies (e.g., NCEP, NOAA/AOML, NASA/JPL) and universities (e.g., Columbia University, New York University, University of California – Los Angeles, University of California – San Diego, University of Maine, University of Hawaii, and FSU). International users include ECMWF, the Royal Netherlands Meteorological Institute, CSIRO (Australia), the National Institute Of Oceanography in India, and the Shanghai Typhoon Institute. The quick-look Pacific fields are also reproduced on a monthly basis in the Climate Diagnostics Bulletin distributed by NOAA. At present, the FSU winds are periodically provided to NCAR for archival by their Data Support Section.





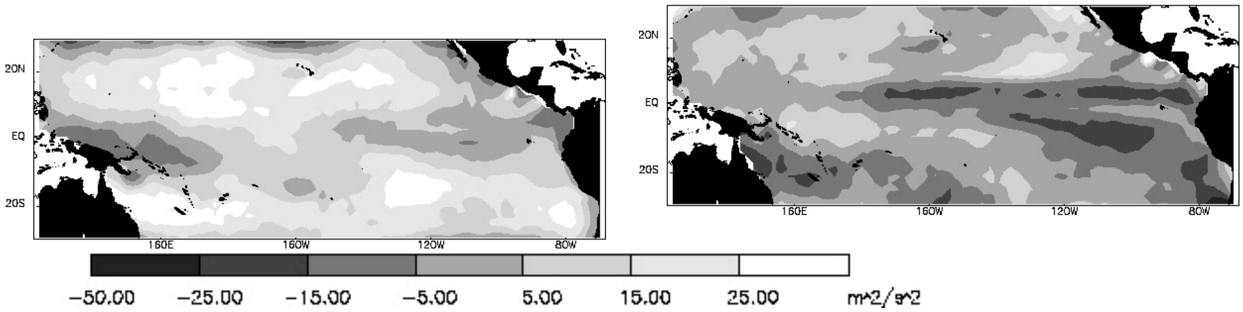


Fig. 1. Mean monthly differences of FSU and scatterometer pseudostress components (FSU minus scatterometer), where zonal pseudostress is on the top row and meridional pseudostress is on the bottom row. The new objective FSU winds (left) are much more similar to the scatterometer winds than the old subjective FSU winds (right). The Meridional differences indicate that neither the subjective or objective FSU winds capture the strong Meridional convergence about the ITCZ. The patterns in the zonal winds are related to the currents. Scatterometer winds are current relative, whereas the FSU winds are earth relative.

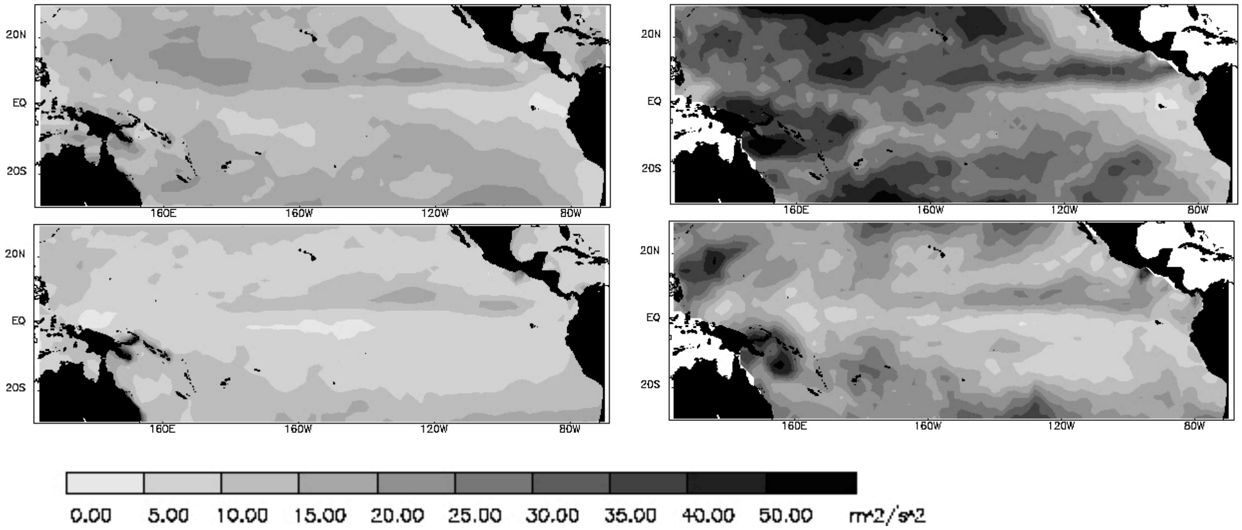
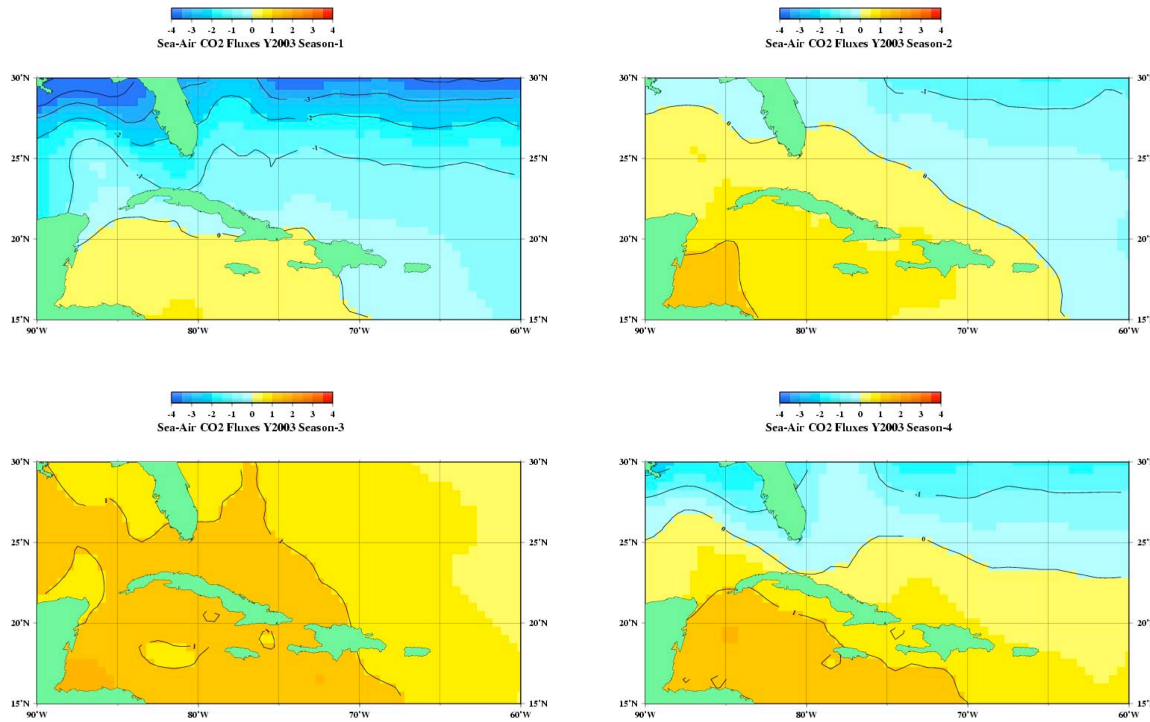


Fig. 2. Standard deviations of monthly differences of FSU and scatterometer pseudostress components, where zonal pseudostress is on the top row and meridional pseudostress is on the bottom row. The new objective FSU winds (left) are much more similar to the scatterometer winds than the old subjective FSU winds (right). The meridional standard deviations have a local maximum about the ITCZ and in the area of the SPCZ. The VOS observation pattern is easily identifiable in the subjective FSU winds.

Document Ocean Carbon Sources and Sinks



Seasonal flux maps for the Caribbean Sea for 2003 based on observations of the Explorer of the Seas and algorithms using remotely sensed SST.

3.28a. U.S. Research Vessel Surface Meteorology Data Assembly Center
by James J. O'Brien, Mark A. Bourassa, and Shawn R. Smith

PROJECT SUMMARY

Accurate estimates of turbulent air-sea fluxes over the global oceans are necessary for ocean modeling, climate modeling, and are a key component of the Climate Observation Program. The Research Vessel Surface Meteorology Data Center (RVSMDC) continues to evaluate the accuracy of turbulent fluxes from in-situ observations, satellite observations, and globally gridded flux fields (e.g., FSU fluxes, national meteorological center reanalyses). These activities specifically target performance measures related to sea surface temperature, sea-level pressure, and air-sea exchanges of heat, momentum, and fresh water as outlined in the Program Plan.

The unique component of the RVSMDC activities is the source of in-situ data: quality-evaluated, automated meteorological observations collected by research vessels (R/Vs). Through an expansion of funding from the NOAA Office of Climate Observation (OCO) to COAPS, the RVSMDC is seeking to obtain marine meteorological data on a routine basis for all U.S. sponsored R/Vs. During the development and pilot project phase of the expansion, the RVSMDC continues to augment its R/V data holdings with observations from the NOAA vessels *Ronald Brown* and *Ka'Imimoana,* as well as observations collected internationally on CLIVAR hydrographic cruises. Initial evaluation of IMET (Hosom 1995) equipped VOS vessels are also underway.

Production of quality-evaluated R/V meteorological observations and turbulent fluxes provides an important data source for validation of the analyses (sea surface pressure, winds, precipitation, sea temperature, and air-sea fluxes) desired by the Climate Observation Program. Benefits of our R/V flux evaluations include uncertainty estimates that will allow future improvements of global flux fields. Future inclusion of vessels operating in polar regions will allow evaluation of fluxes under extreme environmental conditions. R/V observations are too sparse in space-time to validate monthly products, such as an objective version of the FSU winds (Bourassa et al. 2003); however, the R/V observations can be used to validate satellite observations, which can then be used to validate the monthly products. Directly or indirectly, R/V data are an excellent source of comparison data for surface reanalyses (e. g., Smith et al. 2001).

All R/V observations are currently evaluated using an improved automated and visual quality processing system. Through the OCO supported Shipboard Automated Meteorological and Oceanographic (SAMOS) initiative (formerly the HRMM initiative), the RVSMDC is designing a more sophisticated automated quality processing system. The framework for the new system has been established and development of databases and computer tools is underway. Through the SAMOS initiative we have expanded and will continue our interaction with R/V operators, and anticipate improvements in the accuracy of all SAMOS data. Free distribution of our quality evaluated R/V data (http://www.coaps.fsu.edu/RVSMDC/) continues to benefit U. S. and international scientists. Expanding access to quality-evaluated R/V meteorological data is a primary mission of our data center and this activity addresses the Milestones for Dedicated Ship Time and Data and Assimilation Subsystems outlined in the Program Plan.

All activities of the RVSMDC are the responsibility of personnel at COAPS. To complete the activities, we directly coordinate data receipt from the ship technicians, vessel operators, and international data archives. Collaboration continues with Robert Weller, David Hosom, and Frank Bahr at the Woods Hole Oceanographic Institute in regards to the VOS IMET program. During FY 2004, we extended our collaboration with members of several JCOMM panels through the SAMOS initiative, specifically through the 2nd Workshop on High-Resolution Marine Meteorology (Smith 2004a, b). We are building further partnerships with the WMO VOSClim program, the WCRP Working Group on Surface Fluxes

(Smith is a member), the IODE GOSUD project, both the U. S. and international CLIVAR program, GOOS, IOOPC, and the Ocean.US IOOS-DMAC.

RVSMDC activities are managed in accordance to the Ten Climate Monitoring Principles outlined by the NRC. Since our inception with WOCE and TOGA-COARE, the COAPS R/V data center has emphasized the importance of metadata to fully document our data sets. We have a clear focus on data quality and have applied a number of innovative quality assurance (QA) techniques for R/V data. Since the end of WOCE, the data center has been a strong advocate for continued data stewardship for R/V meteorological observations. We continue to call for additional resources to be applied to the remote regions of the oceans (e.g., Southern Oceans), where R/Vs can serve as a vital component of an ocean observing system. From the outset of the SAMOS initiative, the RVSMDC has sought input from scientists, technicians, data and archival experts, and policy makers to ensure that the design and implementation future RVSMDC data quality and distribution practices meet a broad range of user needs. Finally, we continue to provide free and open access to all R/V data, metadata, and documentation at the COAPS surface meteorology data center.

FY 2004 PROGRESS

SAMOS Initiative:

The SAMOS initiative focuses on improving the quality of and access to surface marine meteorological and oceanographic data collected *in-situ* by automated instrumentation on ships. As part of this effort, the NOAA OCO hosted the *2nd High-Resolution Marine Meteorology (HRMM) Workshop* in Silver Spring, Maryland on 15 and 16 April 2004 (Smith 2004a, b). The purpose of the second workshop was to discuss implementation of the recommendations from the *Workshop on High-Resolution Marine Meteorology* held in Tallahassee, FL on 3-5 March 2003 (for details see http://www.coaps.fsu.edu/RVSMDC/marine_workshop/Workshop.html).

Throughout the past year, members of the RVSMDC have been actively promoting the SAMOS initiative and both U.S. and international meetings. We have coordinated efforts by other SAMOS panelist to introduce the SAMOS initiative to the Scientific Committee and Antarctic Research, JCOMM, CLIVAR, and the IODE GOSUD project. Feedback from the scientific and technical community has been supportive and constructive as the RVSMDC begins development of a data collection and distribution system for SAMOS observations.

The expanded OCO funding specifically allows the RVSMDC to coordinate the collection, QA, distribution, and future archival of SAMOS data collected on U. S. research and merchant vessels. The RVSMDC will collaborate with WHOI and SIO to design a ship-to-shore-to-user data pathway,which will support data transmission from each ship to the DAC on a daily basis. A “quick-look” version of the SAMOS data will be available within a few days of receipt at the DAC. The quick-look data will undergo common formatting and automated quality control. Visual inspection and further scientific quality control will result in a “research” quality SAMOS product. The RVSMDC will provide distribution services for the quality-controlled data in formats that meet user needs and will ensure that the original and quality controlled data are submitted to several national data archives.

The RVSMDC activities related to the SAMOS initiative are still in the early stages. The initial design for a ship-to-shore-to-user data pathway is complete. Several steps of this pathway will involve working with our pilot project partners at WHOI and SIO and a team of programmers at the RVSMDC is beginning development of necessary processing codes and display tools.

Another key component of the SAMOS initiative is the development of a metadata profile for each ship providing SAMOS data. A draft SAMOS metadata standard has been developed and is being reviewed by members of the scientific and technical community. A related task includes the development of a SAMOS metadata database at the RVSMDC. The database is being designed and will provide community access to SAMOS metadata. The database will also play a key role in augmenting SAMOS data with important metadata. Additional databases will track the files from arrival to archival and will provide for data quality statistics.

Data quality and distribution:
The enhanced QA system was applied to historical data from the *Ronald Brown* (Jan. 2002 – May 2004, *Revelle* (May – Sept. 2003), *Melville* (May – July 2003), *Meteor* (June 2003 – May 2004), and *Polarstern* (May 2003 – June 2004)[Fig. 1]. Data for the *Ronald Brown* (the only NOAA vessel examined) covered portions of the Pacific and Atlantic oceans. The observations from the *Revelle*, *Melville*, *Meteor*, and *Polarstern* were collected and evaluated as part of our satellite validation efforts. Data from all the vessels are sampled at one-minute intervals and typically include the ship's position, speed, course, and heading along with standard meteorological parameters (e.g., ship- and earth-relative winds, air and sea temperature, atmospheric pressure, humidity, and shortwave and longwave radiation).

Data QA for the *Ronald Brown* continued to reveal significant problems with these data, primarily from the wind sensors (Fig. 2). For the period Jan 2002 – November 2003 an average of 5 - 10% of the wind observations were flagged as suspect. Other parameters tended to have fewer suspect values. Further analysis leads the RVSMDC to suspect that many of the flagged data result from distortion of the airflow over the vessel and inadequate sensor ventilation. Recently, the meteorological sensors have been moved from the old IMET mast on the bow to the bow jackstaff. Analysis of future data will reveal whether or not this move will improve data quality.

The RVSMDC continues to evaluate systematic errors in R/V meteorological data by creating innovative display tools to identify problems related to the direction of air-flow over the vessel. In 2004, the RVSMDC completed a detailed examination of the stack exhaust impact on temperature and moisture data collected on the *Meteor* (Rolph and Smith 2004a). Through this short report we identify ship-relative winds angles from which the stack exhaust will adversely impact the temperature and humidity data. The report goes on to make specific recommendations to resolve this problem. To date we are attempting to make appropriate contacts in Germany so that this report can be properly reviewed. The RVSMDC notes that problems of this nature are not unique to the *Meteor* and we anticipate making future recommendations for sensor relocations on other vessels.

Recently, we have had problems with the postal service delivering data disks sent from the *Ronald Brown*. These data are somehow being lost in route to COAPS. To alleviate this problem, I have requested that the technician on the *Ronald Brown* send his next shipment using certified or somehow tracked mail service. After 2001, we also lost our data connection to the *Ka'Imimoana*. Conversations with PMEL indicated that our data requests had been lost during a period of poor retention of technicians on the *Ka'Imimoana*. Some historical data from the *Ka'Imimoana* for 2002-2004 have been provided by PMEL and are now beginning QC. The problems with the current data delivery protocol (i.e., the technician burning data disks and mailing them to the RVSMDC) provide clear examples of the need for a reliable, fully automated transfer of the underway meteorological data from the vessel to the RVSMDC. Hopefully the new SAMOS data protocol will ensure reliable data delivery.

While tracking down the *Ka'Imimoana* observations it became evident that a need for standardization of data logging for COAPS and NODC exists. Currently the *Ronald Brown* and *Ka'Imimoana* record meteorological data for both COAPS and NODC; however, the parameters and sampling intervals differ. Since the RVSMDC plans to provide quality-processed data to NODC, the logical first step would be for both organizations to receive the same raw data from each vessel. A dialog between NODC and COAPS to coordinate the NOAA scientific computer system data logging is planned (S. Rutz, personal communication, 2004).

We anticipate receiving data from one or two VOS-IMET vessels by the end of 2004. In addition, we periodically receive data from CLIVAR sponsored hydrographic cruises (see http://www.coaps.fsu.edu/RVSMDC/CLIVAR/). Over the next year we will process U.S. CLIVAR data under the current RVSMDC funding; however, we are still seeking resources to process international CLIVAR data.

The value-added data and quality control reports (Rolph and Smith 2004b, c, d) are available from our center at http://www.coaps.fsu.edu/RVSMDC/. The report for the *Polarstern* (Rolph and Smith 2004e) has been provided to the Germans and we are awaiting their approval before distributing these data online. Shipboard data are also available via ftp://wocemet.fsu.edu/pub/woce/rv or pub/rvsmdc/rv and our DODS server (http://www.coaps.fsu.edu/RVSMDC/html/dods.shtml). We are committed to an open data sharing policy so data access is not restricted. Through supplemental funding through NOAA/ESDIM, a majority of the RVSMDC holdings are being subsampled for inclusion in the International Comprehensive Ocean Atmosphere Data Set (I-COADS). We have also opened communication with NODC to ensure the archival of post-WOCE quality-evaluated data.

Data applications:

Quality evaluation continues to show problems with the wind observations from the *Ronald Brown*. In late 2003, the *Ronald Brown* was operating in the Gulf of Mexico and this provided an opportunity to compare the SCS meteorological data from the *Ronald Brown* to observations from the National Data Buoy Center (NDBC) Gulf moorings. The *Ronald Brown* IMET data, with and without QC flags considered, were compared to NDBC Gulf of Mexico buoy data for the periods in which the vessel was within 75 km of any buoy. *Ronald Brown* IMET 1-minute shipboard data was averaged in the same manner as the NDBC buoy data. For example, the 12 UTC wind observation consists of 1142 - 1150 UTC data, vector averaged for the 'continuous winds' and were recorded in 10-minute intervals. The time stamp for the shipboard data averages were assigned the corresponding NDBC time stamp, converted to COAPS time. In addition to the winds, 10-min averages of atmospheric pressure, air temperature, sea temperature, and specific humidity were created; however these ship values were only matched to the nearest hourly NDBC observation (as only hourly NDBC data was available). When QC flags were considered, averages were required to have at least 6 of the 8 possible data values composing the 10-minute average to have 'good' flags otherwise the average was considered missing. Also, in the statistics, if the shipboard average was missing, the corresponding value for the buoy was changed to missing and not used. Atmospheric data were height adjusted to 10 m. The sea temperatures remain at different depths as is apparent in the statistical results. Plots were created for each buoy and variable as well as plots combining all of the ship and buoy data (e.g., Fig. 3). The data were also plotted according to the distance between the vessel and buoy.

When comparing the Ron Brown and buoy data without considering QC flags, the preliminary results demonstrate that, as a whole, the winds were less correlated than the variables of state. The wind speed correlation between the ship and buoys ranged from 17.5 - 74.8% for individual buoys with enough data to calculate a correlation and is 72.8% for all data. The direction data had correlations ranging from 48 - 86.7% per buoy and was 84.9% when all of the data was combined. The meteorological data was much better with pressure correlations ranging from 76.8 - 98.9% (99.1% cumulative) resulting in little uncertainty in the data. The air temperature data were also highly correlated with values from 88.6 - 92.8% (96.2% total). Again there was little variation in the air temperature data as described by RMS of only 0.737 ˚C for all of the data. The sea temperature data was also highly correlated (91.5%) and there were only small variations in the values, hence a small RMS (.677 ˚C). Given a small RMS and the high correlation, a large degree of confidence can be placed in the sea temperature data. The specific humidity data had a high correlation (94.9%), with low RMS and uncertainties in the means, again resulting in a large amount of confidence in the humidity data.

Differences in the statistics between the Ron Brown and NDBC buoys occurred when the comparison was limited to 'good' ship data (those with A, I, G, or Z flags). The correlation of the wind data, direction and speed, were typically greater when the quality control flags were not considered; however, the overall RMS for wind speed dropped from 2.0 to 1.7 ms^{-1} when only 'good' values were compared. The pressure correlation was higher or the same when the flags were taken into account. The air temperature correlation was the same or slightly lower, with a maximum difference of less than 1% between data sets. The sea temperature correlations are very similar between the two data sets. For specific humidity, the maximum correlation difference is 6.4% between the 'good' flagged data and all of the data for buoy 42040. When all of the data is combined (Fig. 3), the only variables to have less than a 90% correlation were the winds with the speed (72.8% and 61.7% respectively) for all of the data and the 'good' data and the direction having 84.9% and 74.8% respectively. Overall, the buoy comparisons suggest that applying QA to the Ronald Brown data can improve the usefulness of the observations; however, some fundamental changes in either instrument location or observing practices is needed to significantly improve the data quality.

R/V observations also have played a key role in estimating the natural variability of surface vector winds. Quantification of this natural variability was use to estimate the extent to which such variability contributes to uncertainty in satellite (scatterometer) observations of surface vector winds. These estimates were applied to current designs, and found to be consistent with error estimates that distinguished between observational errors and differences due to inexact spatial/temporal co-location (Bourassa et al. 2003). Furthermore, the same data were used to estimate the influence of natural variability on accuracy of scatterometers that are early in the planning stage. Considering these aspects prior to building the satellite represents a first for NASA. In simple terms, we are able to provide the NASA engineers with realistic estimates of small-scale variability in the variables that they are planning to measure. These R/V observations clearly demonstrated that problems quite reasonably feared by several members of the Science Working Group would not be serious for any of the designs being considered, for most conditions.

A similar approach is being used to estimate how much vector winds change (on a various spatial scales) in association with rain. Rain modifies the signal received by scatterometers in several ways (Weissman et al. 2002, 2003). Efforts are underway to remove rain-related errors from scatterometer winds. The results of this study will indicate how much wind speed change on the spatial scales that scatterometers used to retrieve vector winds. This information has become critical for determining what types of data can be used as a proxy for truth.

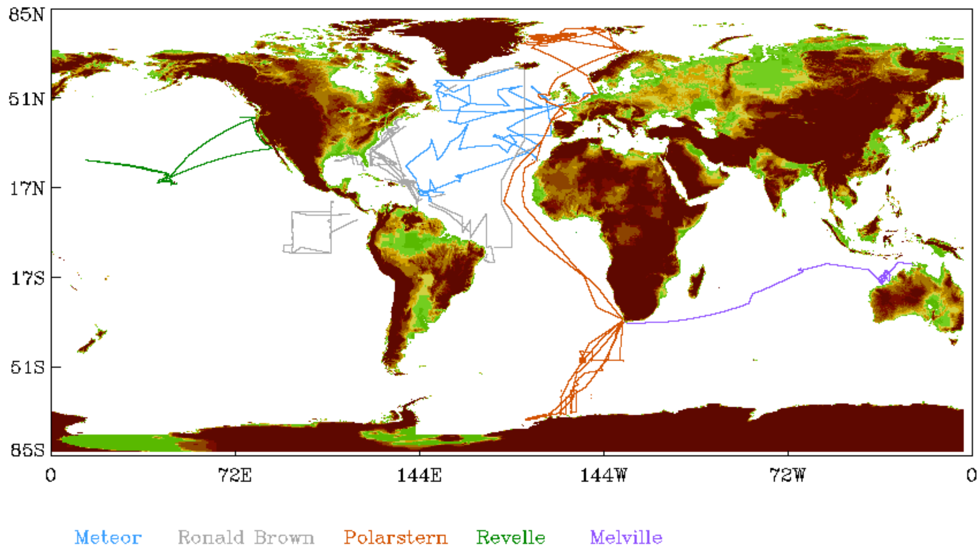


Fig. 1: Ship tracks for research vessel data passing quality evaluation at the RVSMDC between October 2003 and September 2004. Data dates are: *Ronald Brown* (Jan. 2002 – May 2004, *Revelle* (May – Sept. 2003), *Melville* (May – July 2003), *Meteor* (June 2003 – May 2004), and *Polarstern* (May 2003 – June 2004). All data were sampled at 1-minute intervals by automated instrument systems.

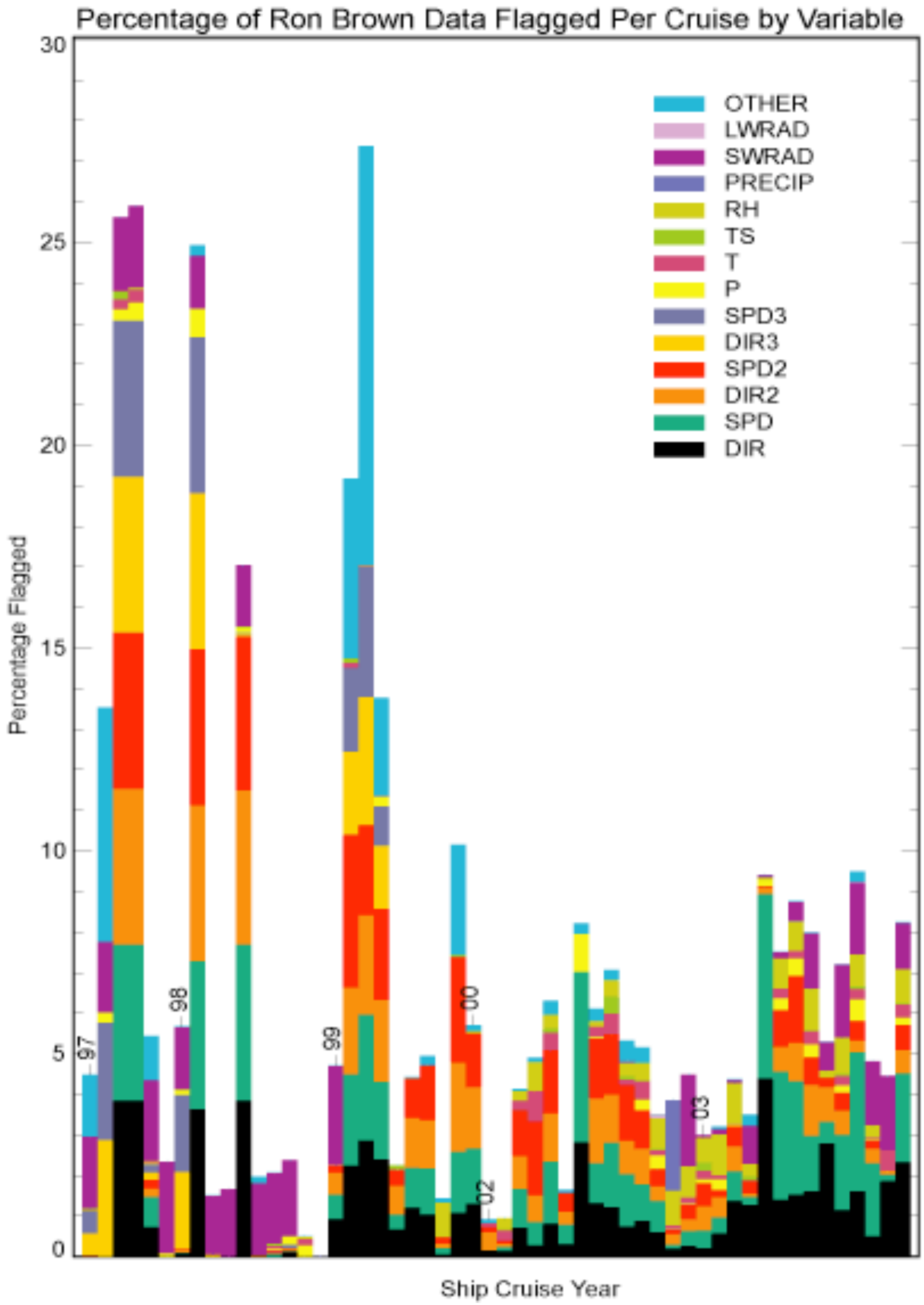


Fig. 2: The total percent of data flagged per cruise on the Ronald Brown. Bars are color coded by measured parameter according to the legend. The length of the color is proportional to the number of flags each of the variables contribute to the total amount of data flagged per cruise.

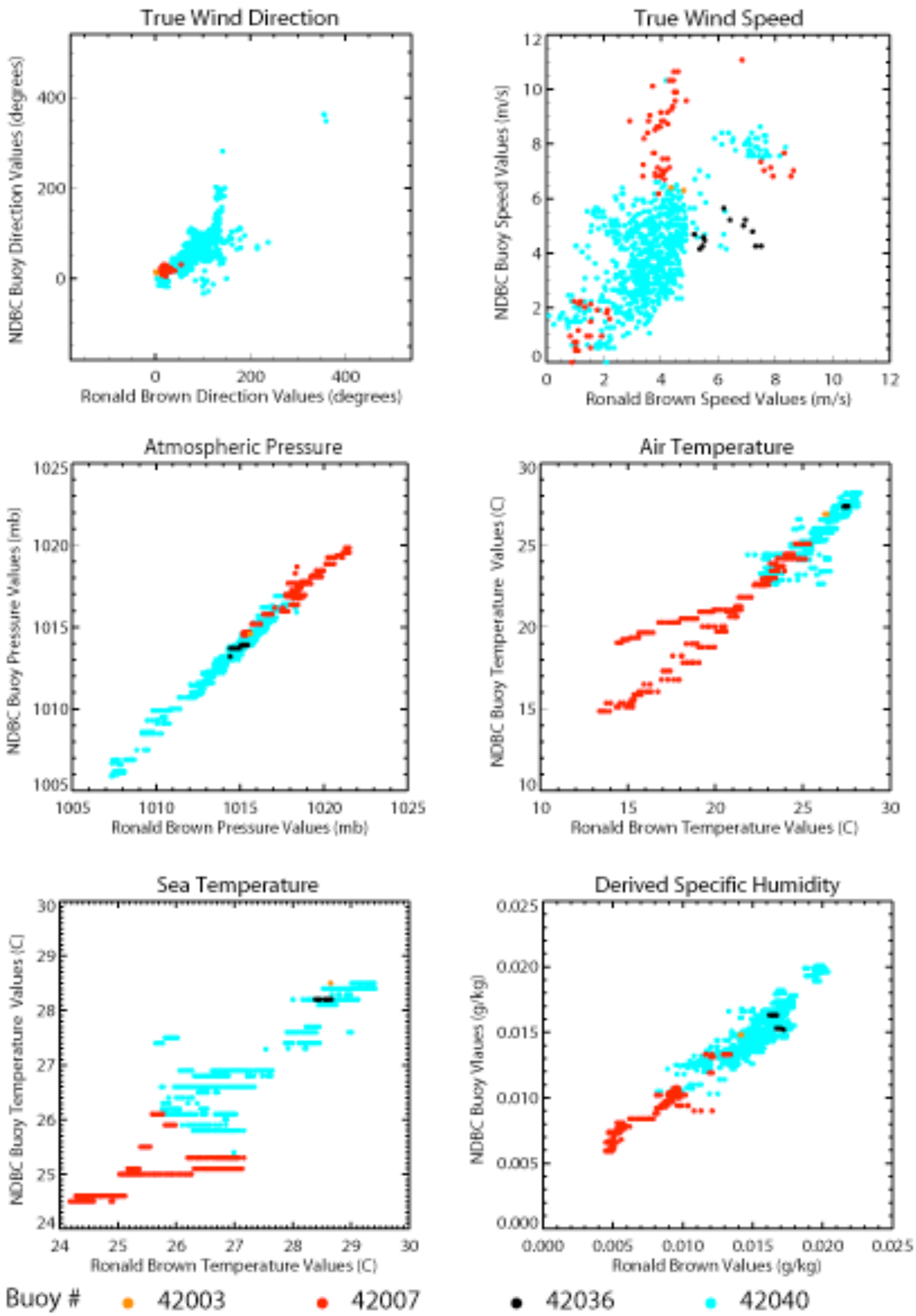


Fig. 3: Scatter plots of height adjusted meteorological data from the Ronald Brown versus four NDBC buoys. All values represent 10-minute averages (see text). The buoys are color coded according to the legend.

THE CENTER FOR OCEAN-ATMOSPHERIC PREDICTION STUDIES
THE FLORIDA STATE UNIVERSITY

Focusing on Improving Automated Meteorological Observations from Ships

The High-Resolution Marine Meteorology (HRMM) community is working to improve the quality of, and access to, surface marine meteorological and oceanographic data collected in situ by automated instrumentation on ships and moored platforms. The purpose of the Second High-Resolution Marine Meteorology Workshop, hosted by the National Oceanic and Atmospheric Administration (NOAA) Office of Climate Observation (OCO), last April, was to discuss implementation of the recommendations from the Workshop on High-Resolution Marine Meteorology held in Tallahassee, Florida on 3-5 March 2003 (for details, see http://www.coaps.fsu.edu/RVSMDC/marine_workshop/Workshop.html).

Shipboard automated meteorological and oceanographic systems (SAMOSs) are an essential component of a sustained ocean observing system. SAMOSs provide platform navigation, surface meteorology, and near-surface ocean data that are ideal benchmarks for new satellite sensors (e.g., WindSat, future National Polar-orbiting Operational Environmental Satellite System (NPOESS) sensors) and global ocean-atmosphere models. SAMOS sampling is adequate to provide accurate estimates of the variability on scales (from subdiurnal) needed for satellite calibration and validation. Sampling rates also are ideal for estimating turbulent air-sea heat, momentum, and moisture fluxes that are critical for climate research and can be used to help understand sources of bias and uncertainty in global model flux fields. SAMOS observations from oceanographic research vessels (R/Vs) are of particular importance since these vessels frequently operate in areas far outside the normal merchant shipping lanes.

The workshop panel recommended that the HRMM community focus first on improving access to SAMOS data collected by U.S. R/Vs and follow that with improving access to data from SAMOSs deployed on merchant ships and international R/Vs operating in the polar oceans. Close collaboration with established mooring programs is anticipated to improve SAMOS metadata, sensor calibration, and data accuracy. The panel identified a list of navigation, meteorology, and near surface ocean parameters required to meet the science objectives outlined at the first workshop. In addition, the panel outlined an effort to create a set of guidelines for metadata to be provided routinely to SAMOS operators.

The panel also intends to petition the University-National Oceanographic Laboratory System (UNOLS) council and other cooperating ship programs to agree to a new data policy whereby access to underway meteorology and thermosalinograph data would be free and open by default, and the data would be exempt from the current practice of a 2-year proprietary hold by chief scientists. A chief scientist would have to specifically request any hold on these data. Free and open access will allow SAMOS observations to become part of a sustained ocean observing system, making these data readily available for use by the climate research, modeling, and remote sensing communities.

The panel plans to seek international participation through the World Meteorological Organization (WMO) Volunteer Observing Ship Climate (VOSClim) program, World Climate Research Program (WCRP) working group on surface fluxes, the WCRP Climate Variability and Predictability (CLIVAR) hydrographic program, and the International Ocean Carbon Coordination Project (IOCCP). Finally, the panel agreed that periodic HRMM workshops provide an important forum for the exchange of ideas and methods. Future workshops will include additional input from data users and developers of new SAMOS technology.

The panel, chaired by Shawn R. Smith, included representatives from the scientific and operational marine observational communities. Participants represented six NOAA facilities (Environmental Technology Laboratory (ETL), Office of Oceanic and Atmospheric Research, National Climatic Data

Center, National Oceanographic Data Center, National Weather Service/National Centers for Environmental Prediction, and Pacific Marine Environmental Laboratory), the Brookhaven National Laboratory, and the U.S. Coast Guard (USCG). The university community was represented by the Woods Hole Oceanographic Institution (WHOI), the Scripps Institution of Oceanography (SIO), the University of Miami, Columbia University, and Florida State University. International representatives were present from the Commonwealth Scientific and Industrial Research Organization (CSIRO) (Australia), the Joint WMO-Intergovernmental Oceanographic Commission's Technical Commission for Oceanography and Marine Meteorology, WCRP, and the Global Ocean Observing System (GOOS). Program managers from NOAA OCO and the National Science Foundation were also present.

Progress and New Initiatives:
The HRMM community is focusing on improving access to quality-controlled SAMOS data for scientific and operational users, improving the accuracy of SAMOS measurements, and providing training for data collectors and improved metadata to users. The HRMM community has (1) established a data assembly center (DAC) for SAMOS observations from U.S.-sponsored R/Vs and VOS, (2) begun developing a roving surface flux standard instrument suite for onboard instrument comparison, (3) outlined a "Handbook on Meteorological Measurements at Sea." (4) initiated communication with vessel operators (e.g., NOAA, UNOLS, USCG), and (5) solicited support and input from the U.S. and international marine and climate science communities. Several pilot projects were outlined by the second HRMM panel that will be initiated in 2004-2005.

The DAC was established specifically to coordinate the collection, quality control, distribution, and future archival of SAMOS data. The DAC, funded at the Florida State University (FSU) in 2004, will collaborate with WHOI and SIO to design a ship-to-shore-to-user data pathway for U.S. research vessel SAMOS data. In the past, the data flowed from ship to shore only in a delayed mode with a 3-month to 2-year lag between collection and availability to the user community. The new vision will support data transmission from each ship to the DAC on a daily basis. A "quick-look" version of the SAMOS data will be available within a few days of receipt at the DAC. The quick-look data will have undergone common formatting and automated quality control. Visual inspection and further scientific quality control will result in a "research"-quality SAMOS product. The DAC will provide distribution services for the quality-controlled data in formats that meet user needs and will ensure that the original and quality-controlled data are submitted to several national data archives.

Several improvements to the accuracy of SAMOS data are being investigated. Instrumentation developers at NOAA ETL and WHOI are designing a two-part roving standard instrument suite that will be used for onboard validation and comparison with a research vessel's permanent SAMOS. The first component of the roving standard will be a state-of-the-art turbulent flux instrument suite that will be installed to provide the best possible measure of air-sea fluxes and surface meteorology. A second set of traditional marine weather instruments will be located near the R/V's SAMOS instruments to provide side-by-side comparison with the permanent shipboard sensors. A trained technician will travel with the roving standard and work with the R/V's technician (over the course of several weeks at sea) to identify discrepancies between the roving and standard and the R/V SAMOS measurements. A pilot project to compare the state-of-the-art flux sensors and an R/V SAMOS is planned for 2005.

Another initiative to improve data accuracy will provide for computational fluid dynamics (CFD) modeling of the airflow around vessels. Research at the Southampton Oceanography Centre, WHOI, and other institutions revealed that modeled airflow can be used to determine optimal sensor locations. CFD results also can be used to adjust meteorological measurements to remove biases caused by the airflow around various ship structures. Discussions are under way to complete CFD modeling on new R/Vs during their design phase.

The focus of the training activities lies in the production of a handbook or guide to best procedures and practices for meteorological measurements at sea. This was first proposed by the WCRP/Scientific Committee on Oceanic Research Working Group on Air-Sea Fluxes and adopted at the first HRMM Workshop at FSU in 2003. The handbook is aimed at the seagoing research community and ships' technical staff. Topics will include information on preferred sensor location, calibration, in situ comparisons, documentation, metadata, bulk flux methodology, and measurement error. Plans are for a dynamic handbook that will be available online. Users will be able to download relevant computer code, specifications, and technical information whether on land or at sea.

Future Activities:
At the second HRMM workshop, the panel decided to focus initially on U.S. research vessel SAMOS data. Clearly there is an opportunity to expand this initiative to the international marine community. The panel specifically noted the importance of vessels operating in the polar oceans and identified polar R/Vs as the first international vessels to integrate into the network of routine SAMOS measurements. The polar oceans play a key role in global ocean-atmosphere circulations, and R/Vs provide platforms of opportunity to observe these regions. The panel discussed participation in the upcoming International Polar Year as a possible way to initiate inclusion of polar SAMOS observations into the network.

International collaboration is expected to continue and be expanded in the future. The goal of establishing a sustained global ocean observing system will involve contributions from many nations. The international fleet of R/Vs and SAMOS-equipped VOS will be a key component of that observing system, providing data for air-sea flux estimates and benchmark observations for global data assimilations and new satellite sensors. The HRMM community intends to expand its collaboration with ongoing international climate programs (e.g., CLIVAR, GOOS).

Improving the availability, accuracy, and quality of SAMOS measurements will require a wide range of technical and scientific expertise. For example, there is a need to develop more robust sensors for severe ocean environments, to expand broadband communication between ships and shore, and to provide education on best practices for SAMOS. User input also is critical to ensure that the HRMM community provides products that are useful to modelers, oceanographers, and meteorologists. User input has already resulted in improved data quality, and the panel expects this process will continue. The HRMM community encourages members of the AGU to provide input toward the development of a sustained network of SAMOSs on research vessels and VOS.

The Second High-Resolution Marine Meteorology Workshop was held at NOAA's Office of Climate Observation on 15-16 April 2004, in Silver Spring, Maryland.

3.29a. *In Situ* and Satellite Sea Surface Temperature (SST) Analyses
by Richard W. Reynolds

PROJECT SUMMARY

The purpose of this project is to focus on improvements to the climate-scale SST analyses produced at NOAA as described by Reynolds and Smith (1994) and Reynolds et al. (2002). This effort is designed to support the development of an ocean climate observing system. The analysis is done by optimum interpolation (OI) with a separate step to correct any large-scale satellite biases relative to the in situ data. The analysis uses infrared (IR) satellite data from the Advanced Very High Resolution Radiometer (AVHRR) and in situ data from ships and buoys. In this proposal we discuss our progress and our plans to improve these analyses. The improvements include the development of better bias corrections, the use of new SST data sets and the development of better error statistics. We also present a discussion of an objective method to determine where addition buoy data are needed for improved climate SST.

One of the important goals of the Sustained Ocean Observing System for Climate is to improve the SST accuracy over the global ocean. For this purpose we evaluated the adequacy of the recent in situ network. Because of the high coverage of satellite data, in situ data used in the analysis tends to be overwhelmed by satellite data. Thus, the most important role of the in situ data in the analysis is to correct large-scale satellite biases. Simulations with different buoy densities showed the need for at least two buoys on a 10^o spatial grid. Using this criterion, regions were identified where additional buoys are needed, and a metric was designed to measure the adequacy of the present observing system.

The present version of the OI uses infrared (IR) satellite data from the Advanced Very High Resolution Radiometer (AVHRR) instrument. A study was completed which showed a clear advantage if satellite SST retrievals from Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) were used in the OI analysis. We are presently involved in modifying the code to do this and to reevaluate the OI error statistics.

Richard W. Reynolds is the chair of the SST and sea ice working group which is shared by two GCOS panels: the Ocean Observation Panel of Climate and the Atmosphere Observation Panel of Climate. This proposed work is part of the work of the working group. The working group membership is a broad group of interested national and international scientists. All work presented here follows the Ten Climate Monitoring Principles.

The funds requested for this proposal support work at NCDC. However additional funds at the International Research Institute (IRI) are requested in the added tasks section to support an evaluation of SST analyses using atmospheric models. In addition, the National Center for Environmental Prediction (NCEP) runs the OI analysis operationally at no cost to this project. Information on the analyses and the analyzed fields themselves can be found at: http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/.

FY 2004 PROGRESS

During FY2004, we have made significant progress in two main areas.

1. Design of an in situ SST network to improve the SST analysis

To design an effective and efficient in situ network, we first determined a maximum acceptable error. Following Needler et al. (1999) we specify that the monthly SST error must be less than or equal to 0.5^{o}C on a 5^o spatial grid. This error must include random, sampling and bias errors. The random and sampling error can be determined directly from the OI or from an optimum average (OA) procedure. We found that the sampling and random errors using in situ and AVHRR data were always less than 0.3^{o}C on a monthly 5^o grid. These errors were low because of the high density and full coverage of satellite data. The regions with the largest errors were cloud-covered regions where IR data are limited. The use of global microwave satellite data, which can retrieve SSTs in cloud-covered regions, would further reduce the errors.

Biases occur with all satellite data due to instrument and algorithm problems. For AVHRR typical biases are 0.2 to 0.5ºC. However, AVHRR biases have reached between 2 to 3ºC over the tropical oceans following the 1982 volcanic eruptions of El Chichón and the 1991 eruptions of Mt. Pinatubo. Unfortunately, it is not possible to predict when biases of this size will occur. Thus, it is necessary to have an in situ network that will ensure a final product with acceptable bias errors.

To examine the impact of in situ data on satellite bias correction, the OI was computed with simulated biased satellite data and simulated unbiased buoy data. The maximum satellite bias error was selected to be 2ºC as a worse case. This will be defined as the "potential satellite bias error." Thus, the potential satellite bias error would be 2ºC if there were no in situ data to correct the bias.

The data density of the present in situ network was evaluated to determine where more buoys are needed. These buoys could be either moored or drifting. However, because of the high cost of moored buoys they will be assumed to be drifters. To evaluate this requirement using actual observations, it is necessary to determine how to combine ship and buoy data in the results. Because ship observations are noisier (random error of 1.3°C, Reynolds and Smith 1994) than buoy observations (random error of 0.5°C), roughly 7 ship observations are required to have the same accuracy of one buoy observation. Therefore, an equivalent buoy density is defined as: $n_b + n_s/7$, where n_b and n_s are the number of buoys and number of ships in a 10º box, respectively.

The equivalent buoy density was defined for each month, and then averaged seasonally to indicate where additional buoys need to be deployed. An example is shown in Figure 1 for July - September 2004. Boxes poleward of 60°N and 60ºS were not shown along with boxes with less than 50% ocean by area, as well as boxes in Hudson Bay and the Mediterranean Sea. The figure shows a clear need for additional buoys in the middle latitude Southern Hemisphere oceans. Please note that this figure is completely defined by the in situ data distribution of ships and buoy.

A measure of the performance of the in situ observational system for SST can be calculated from these results. This is done using the potential satellite bias error as a function of equivalent buoy density. The individual potential satellite bias error values can then be averaged spatially. This is described in detail in Zhang et al. (2004) which accompanies this report. The results of this study have already had an influence on future buoy deployments. The NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) is using figures like Figure 1 to guide surface drifting buoy deployments.

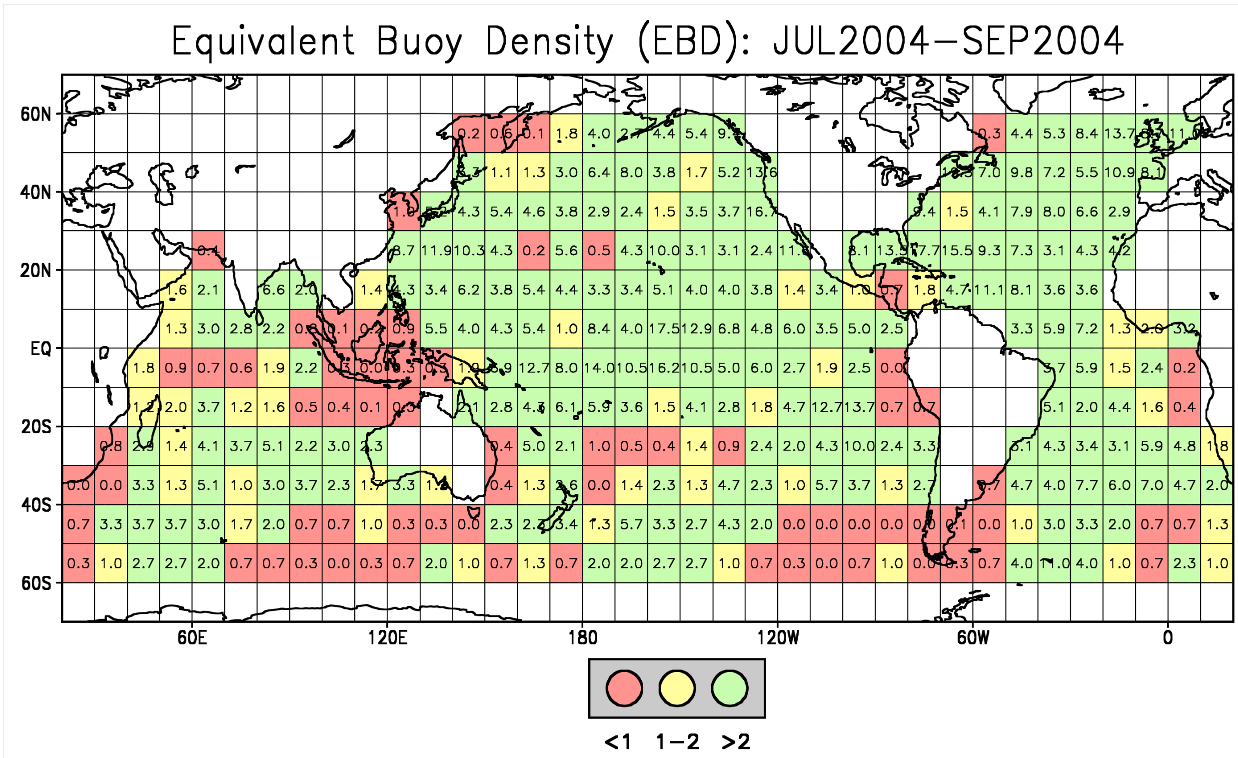


Figure 1. Seasonally (July – September 2004) averaged monthly equivalent buoy density (EBD) on a 10º grid. EBD includes contributions from both buoys and ships, accounting for their typical random errors. Green shading indicates where *EBD*≥2 and no more buoys are needed. Red shading indicates critical regions where *EBD*<1 and two more buoys are needed. Yellow shading indicates 1≤*EBD*<2 and one more buoys is needed.

2. Improve the SST analysis by improving the analysis method and the use of additional data

The present version of the OI uses infrared (IR) satellite data from the Advanced Very High Resolution Radiometer (AVHRR) instrument. A study was completed and is now published (Reynolds et al. 2004) to evaluate the impact of satellite SST retrievals from Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) on the OI analysis. The results of the intercomparisons showed that both AVHRR and TMI data have biases that must be corrected for climate studies. The addition of TMI data clearly improved the OI analysis accuracy without bias correction, but was less significant when bias correction was used. However, there are areas of the ocean with limited in situ data and restricted AVHRR coverage due to cloud cover, and the use of both TMI and AVHRR should improve the accuracy of the analysis in those areas. It is planned to recompute the OI analysis for the entire time period using additional satellite data.

The OI code has been modified to use multiple satellite products. In addition, the spatial error covariances have been recomputed. We did the correlation scales by fitting a Gaussian function to satellite data as we did in Reynolds and Smith (1994). However, there were two important differences. The first was to determine the scales using periods without large satellite biases. The second was to reduce the weights at points far from the data point of interest. Both methods will significantly reduce the spatial scales which will increase the spatial detail.

NCEP presently runs the operational version, which has not been changed since 2002. To make these changes operational it will be necessary to get the entire OI analysis procedure operational at NCDC. A programmer (Chunying Liu) has been hired to get the OI code running at NCDC so that this can be done. At this time we are getting the codes to run with operational data available at NCDC.

3.30a. Monitoring Ice Thickness in the Western Arctic Ocean

by Jackie Richter-Menge, and co-investigators/collaborators
H. Melling, J. Overland, R. Lindsay, J. Zhang, and D. Perovich

PROJECT SUMMARY

Rationale:

Recent studies indicate that the sea ice cover is undergoing significant climate-induced changes, affecting both its extent and thickness. For instance, satellite-derived estimates of maximum ice extent suggest a net reduction between 1978 and 1996, at an average rate of –3% per decade (Parkinson et al. 1999). A recent report by Comiso (2002) indicates an even more rapid reduction in the perennial sea ice cover, of –9% per decade. Data on the ice thickness, derived from submarine-based upward looking sonar, also suggest a net thinning of the sea ice cover since 1958 (Rothrock et al. 1999; Wadhams and Davis 2000; Tucker et al. 2001). It is important that we continue and expand efforts to monitor these changes to (a) improve the fundamental understanding of the role of the sea ice cover in the global climate system and its influence on the Arctic ecosystem and (b) take advantage of the sensitivity of the sea ice cover as an early indicator of the magnitude and impact of climate change.

The extent of the sea ice cover is effectively monitored from satellite platforms using passive microwave imagery. Monitoring changes in the ice thickness is more problematic. As with ice extent, the ideal platform for monitoring ice thickness is a satellite because it provides a full-basin perspective. Until recently, no technique had been adequately developed to obtain reliable satellite-based measurements of ice thickness. Exciting new results, reported by Laxon et al. (2003), suggest a possible breakthrough in the use of satellite altimeter measurements of ice freeboard to determine the mean ice thickness field and it variability. As this and other satellite-based technologies develop, we must also find ways to make more effective use of ice thickness measurements collected from other platforms, including submarines, aircraft, seafloor moorings, and drifting buoys. While these measurement platforms have spatial limitations, they can play a central role in the validation and calibration of satellite-based instruments. Further, their capacity to collect data at higher temporal resolutions can provide information necessary to understand and attribute observed changes in the ice thickness.

Brief statement of objectives:

The primary objective of this proposal and the related proposal "Monitoring the Eurasian Basin of the Arctic Ocean" is to establish and maintain a large-scale sea ice thickness observing system. The establishment of two distinct elements recognizes the different logistical challenges in the western and eastern sectors of the Arctic region. This work focuses specifically on measurements within the western sector of the Arctic. This sector of the Arctic is currently more accessible and, therefore, makes it feasible to conduct a program involving instrumentation that must be maintained after deployment. Within the western sector of the Arctic, we propose to initiate an array of moored ice profiling sonar (IPS) (Melling and Riedel 1996) and drifting ice mass balance buoys (IMB) (Perovich and Elder 2001).

The IMB buoys are equipped with thermistor strings, which extend through the thickness of the ice cover, and acoustic sensors monitoring the position of the top and bottom surfaces of the ice. These instruments provide a time series of snow accumulation and ablation, ice mass balance, internal ice temperature fields, and temporally-averaged estimates of ocean heat flux. Together, these data not only provide a record of changes in the ice thickness, but equally important they provide the information necessary to understand the source of these changes. This is critical to extending the result from these individual sites to other regions of the Arctic. The IMB buoys are also equipped to measure position, sea level pressure (SLP), and surface air temperature (SAT). The drift pattern of the buoys provides information on the circulation pattern of the sea ice cover. Data on SLP and SAT are designed to be compatible with similar data collected from the more basic drifting buoys deployed under the International Arctic Buoy Program (IABP, http://iabp.apl.washington.edu/). The moored upward looking sonar measure ice draft and velocity as the ice drifts overhead, providing a measure of the ice thickness distribution at a specific location within the Arctic Basin.

Instrumentation within the large-scale observing network will be located to complement existing measurement sites and activities and to take advantage of historical data records. Specifically, we look to augment the data currently being collected at the North Pole Environmental Observatory (NPEO, http://psc.apl.washington.edu/northpole/), by the IABP, and from SCICEX cruises. Specific site locations will be determined using models of ice motion, which incorporate recorded observations. Data from the observation sites will be combined with data from other sources to produce annual reports on the state of the sea ice cover, including both its extent and thickness. A contextual setting for current data will be established by summarizing earlier observations in the Western Arctic of sea ice mass balance over an annual cycle, which begins in 1957. We will also investigate the availability of data in the Russian literature, which is likely to cover the Eastern Arctic.

This ice thickness observing network is a component of NOAA's Arctic Climate Observing System (ACOS), which is a contribution to the NOAA Climate Observations and Analysis Program. The ACOS is coordinated out of NOAA's Arctic Research Office.

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Modeling. A sea ice dynamics model (Zhang et al. 2003) was used to help determine the best location for establishing the mooring site CH01 (see item 3 below). The model is designed to assimilate ice velocity and ice extent data and was used to generate simulations of ice thickness distributions that cover the period from 1948 to 2002. With regard to the site CH01, the model was applied with the objective of optimizing the location of instrumentation to monitor changes in the mean annual thickness of the sea ice cover in the basin. During 2004, we used this same model to investigate how to best monitor temporal changes in the spatial patterns of the ice thickness. This was done using a linear regression analysis to determine the points that maximize the explained variance for the most important principle components (PC), generated from an empirical orthogonal function (EOF) analysis. Preliminary results are presented in Figure 1. Figure 1a shows the spatial pattern of total variance explained by a single point, which produces a maximum of 37% in the Eastern Siberian Sea. Figure 1b shows the spatial pattern of the additional variance explained by a second point, assuming that ice thickness measurements continue to be made at the North Pole Environmental Observatory (NPEO). In this case, the maximum additional explained variance is 19% in the northeastern portion of the Beaufort Sea; however it is apparent that many locations in the Beaufort and Chukchi Seas do nearly as well. Figure 1c shows the spatial pattern of the additional variance explained by a third point, assuming the continued measurement of ice thickness at the NPEO and CH01. The maximum point is in the East Siberian Sea, adding 15% to the explained variance. This analysis suggests that, collectively, data from these three sites produce results that explain 66% of the total variance in temporal changes in the spatial patterns of ice thickness. A paper on these results in near completion, and will be submitted to Journal of Physical Oceanography for peer review in 2005.

1. *Equipment Fabrication*: Completed the fabrication of second mooring, equipped with an ice profiling sonar (IPS), acoustic Doppler current profiler and release system. Fabricated 6 ice mass balance (IMB) buoys. One of the IBM was fabricated for deployment in support of this specific project. The other 5 were fabricated for deployment in support of the companion project, "Monitoring the Eurasian Basin of the Arctic Ocean".
2. *Maintenance of Ice Profiling Sonar Site CH01, on the Chukchi Plateau*. The mooring site, deployed on 19 August 2003 and designated site CH01, was successfully recovered on 19 September 2004. The site was re-established on the same day with the successful deployment of a second mooring, also

equipped with an IPS. The CH01 site is located on the Chukchi Plateau at 75°06.0’ N, 168° 00.0’ W (Figure 2). Site maintenance in 2004 was conducted by the *USCG Healy*.

3. *Ice Mass Balance Buoy Deployment*. A drifting buoy, equipped to measure and attribute changes in the thickness of the ice cover, was deployed from the *CCGS Louis St. Laurent* 19 August 2004. The buoy was installed at 76°10.02’ N, 141°10.32’ W. In collaboration with the Arctic Group at the Woods Hole Oceanographic Institute, this IMB was collocated with a newly developed ice-tethered profiler (ITP). The ITP, developed with funding from the National Science Foundation, is designed to measure ocean temperature and salinity (http://www.whoi.edu/itp/). Combined, the IMB and ITP provide a more comprehensive data set on the evolving characteristics of the ice-ocean environment. The deployment location of this buoy (IMB 7413) and the IMBs launched as part of the companion project “Monitoring the Eurasian Basin of the Arctic Ocean”, is shown in Figure 2.

4. *Ice Mass Balance Buoy Recovery*. A drifting IMB deployed in August 2003 in the Beaufort Sea as part of this program, was recovered on 24 August 2004. The recovery took place during the same cruise described in item 4 above. The recovered buoy was operational from 31 August 2003 until 28 July 2004. The drift track of this buoy is shown in Figure 3. Recovery of the buoy revealed that the buoy had stopped operating because it tipped over in a melt pond, causing the satellite transmission antenna to be under water. This buoy will be returned to CRREL and prepared for redeployment.

5. *Data Collection and Analysis*. The processing and quality control of the data collected from the drifting buoys is being done in coordination with the companion NOAA/SEARCH project “Monitoring the Eurasian Basin of the Arctic Ocean”. These data are being archived at the World Data Center for Glaciology.

   We have completed the analysis of the data from the IMB buoy deployed in the Beaufort Sea in August 2003 and recovered this fall (see item 5) over its period of operation (Fig. 4). The data from this buoy serve to illustrate the advantages of the buoy design which permit us to monitor and attribute changes in the thickness of the ice cover. Specifically, we can observe whether the change in the thickness of the ice cover was the result of atmospheric or oceanic forcing. In this case, the data show the offset in surface and bottom melting that is typically observed. When the buoy was installed, surface melting was at its peak for the season and, in fact, snow had begun to accumulate. While surface melting had ended, bottom melting was still under way. When bottom melting came to an end, in mid-October, the ice thickness had been reduced by another 25 cm. By the beginning of November, almost 25 cm of snow had accumulated on the top of the ice and the ice had cooled enough to begin bottom growth. Bottom growth continued until mid-may, increasing the ice thickness by 135 cm, from 60 cm to 200 cm. In early June, both the snow cover and bottom surface of the ice cover began to melt. Rapid melting of the snow and ice surface occurred in mid-June. A notable increase in the rate of melting at the bottom surface began in early July. When the IMB buoy stopped operating on 28 July, 25 cm of ice had been lost on the top surface of the ice and 50 cm was lost at the bottom surface. At this point in time, the ice had experienced a net gain of approximately 60 cm in thickness.

   With the successful recovers of data from the instruments at the mooring site CH01, we will analyze and document the annual cycle of ice thickness at this location during fiscal year 2005.

6. *Webpage Development*. We have begun the construction of a webpage, designed to present the data in near real time, http://www.crrel.usace.army.mil/sid/IMB/. The webpage has links to related products, including IABP (http://iabp.apl.washington.edu/) and Arctic Theme page (http://www.arctic.noaa.gov/). The webpage also includes general background information, serving as a tool for educational outreach.

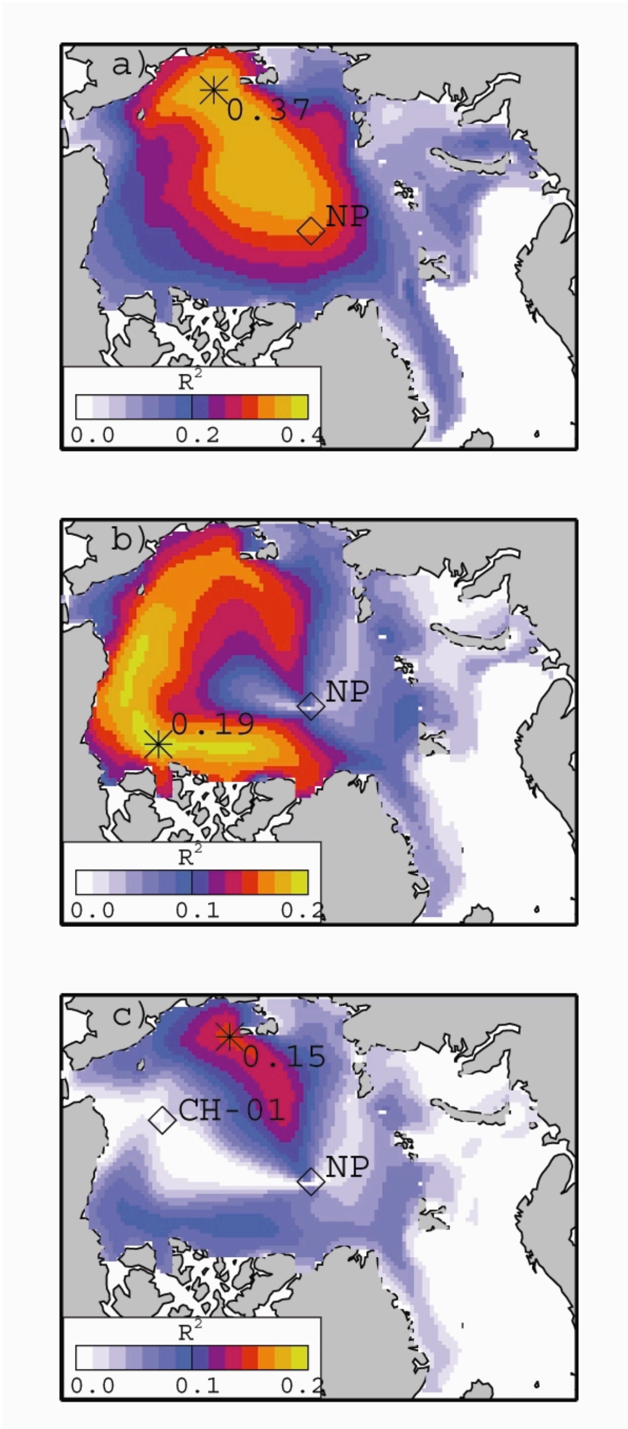


Figure 1. Preliminary results indicating the optimum location of instrumentation to monitor temporal variability in the mean ice thickness of the Arctic sea ice cover; (a) assumes a single instrumentation location, (b) assumes 2 locations, one being the existing NPOE and (c) assumes 3 locations, one being the NPOE and the other being the existing CH01 mooring site. These results are produced by applying linear regression analysis to sea ice dynamics model simulations of the ice thickness distribution.

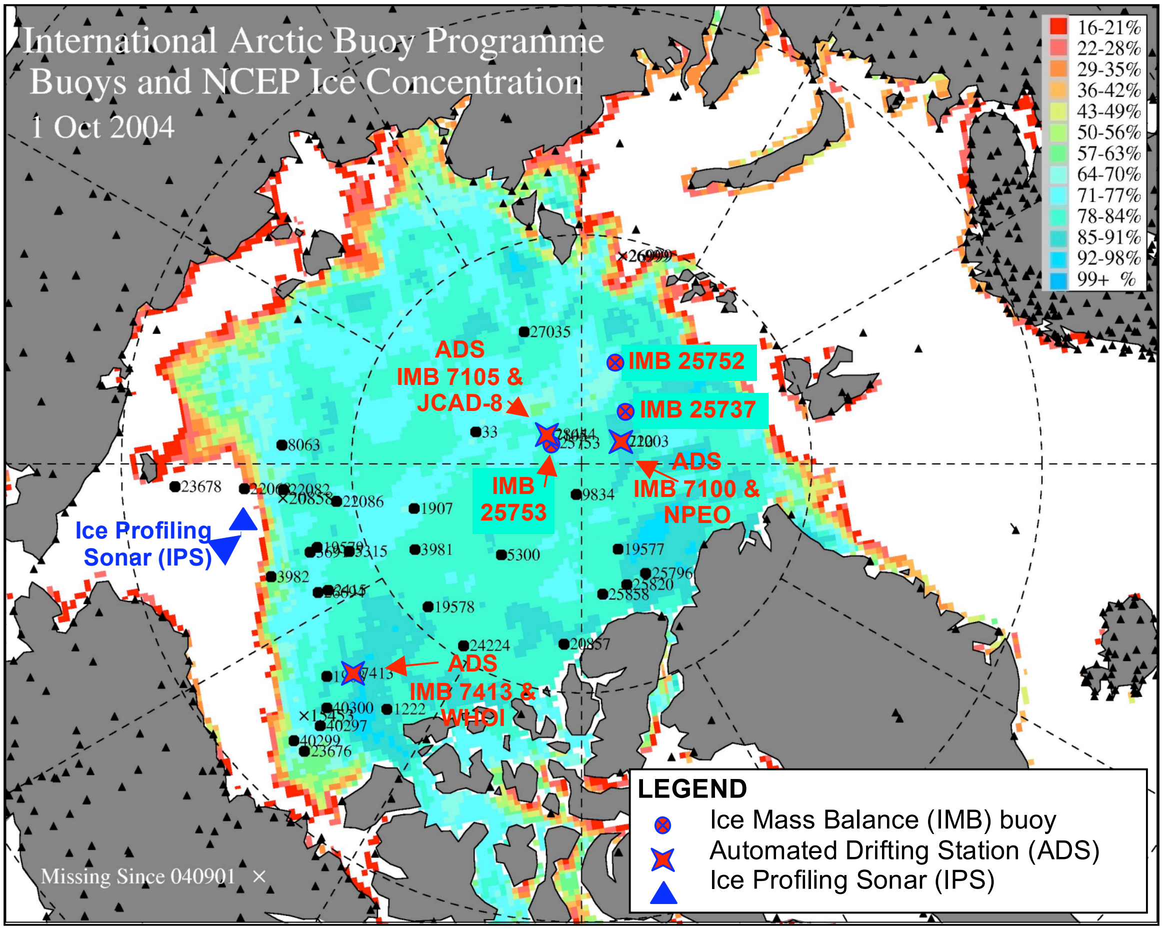


Figure 2. Current locations of Ice Mass Balance (IMB) buoys. The locations of "solo" IMB buoys are marked by red dots, while IMB buoys deployed in Automated Drifting Station (ADS) are marked by red stars. The positions of other IABP buoys (black dots) and the Ice Profiling Sonar (IPS, blue triangle) are also shown. The sea ice concentration data were obtained from the National Center for Environmental Prediction.

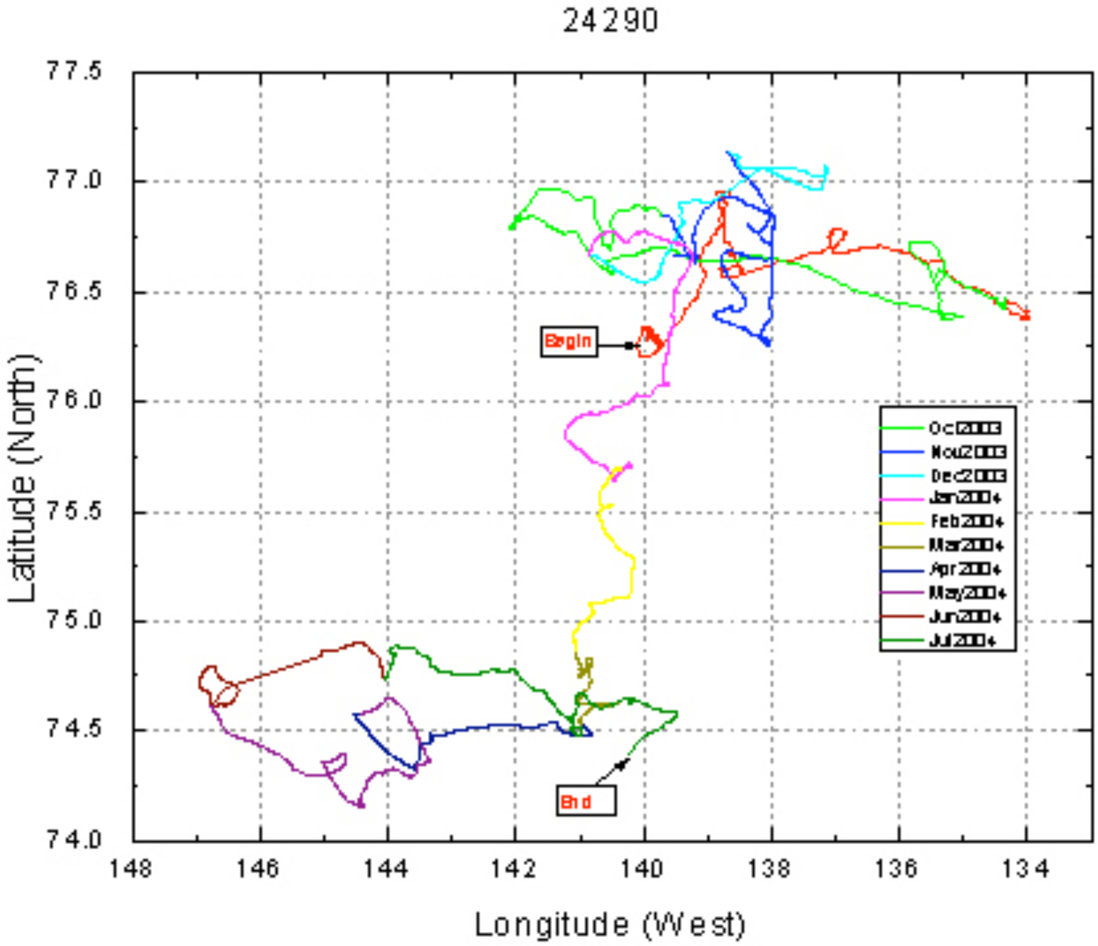


Figure 3. Drift track of IMB 24290, deployed 31 August 2003 in the Beaufort Sea. This IMB was operational until 28 July 2004 and was recovered on 24 August 2004.

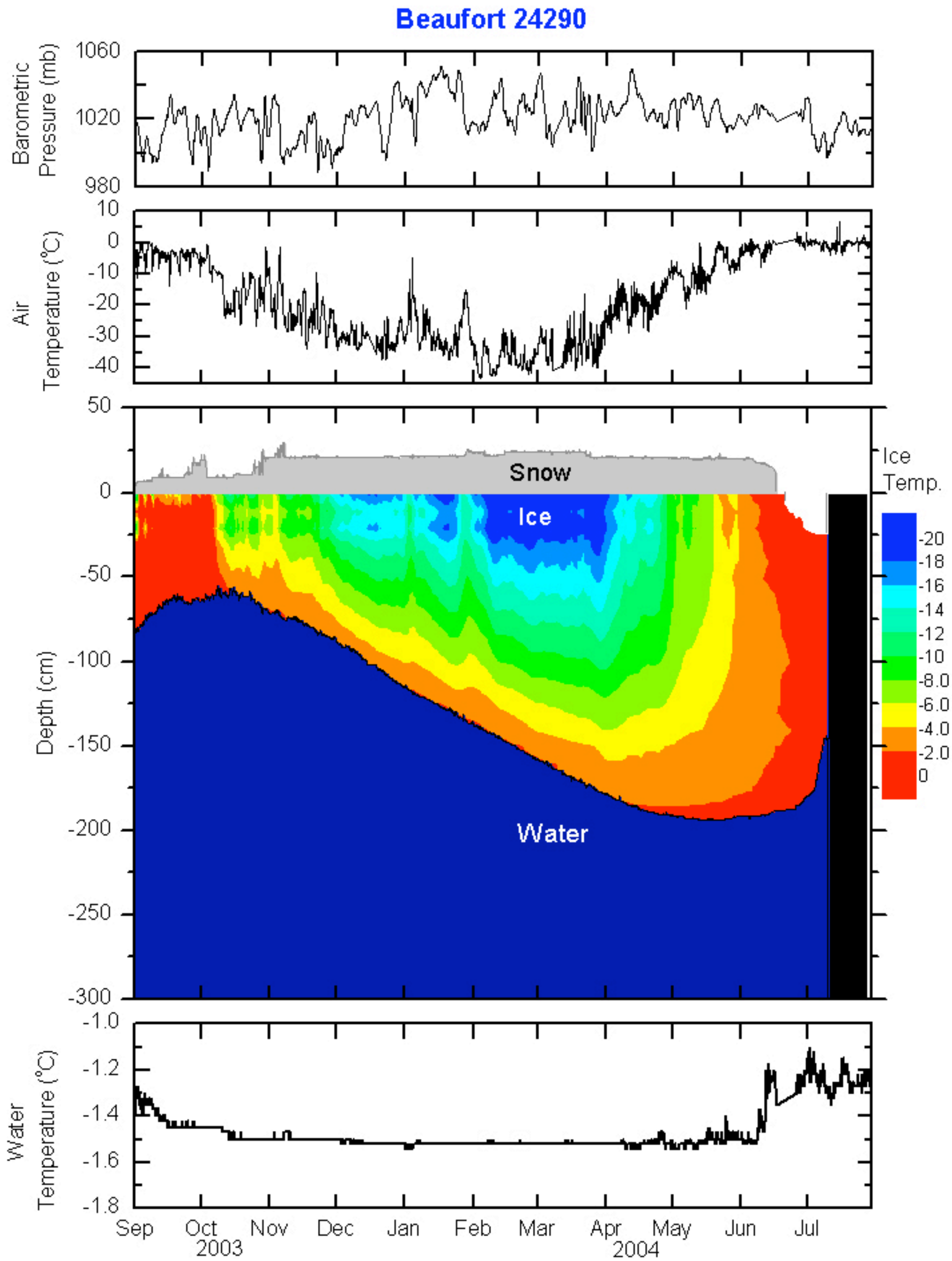


Figure 4. Data collected from IMB 24290, deployed in the Beaufort Sea and operational from 31 August 2003 to 28 July 2004.

3.31a. Monitoring Eurasian Basin of the Arctic Ocean

by Ignatius G. Rigor

PROJECT SUMMARY

Co-Investigators and Collaborators: Andy Heiberg, University of Washington; Magda Hanna, National Ice Center (NIC); Igor Dmitrenko, International Arctic Research Center (IARC); Takashi Kikuchi, Japan Agency for Marine-Earth Science and Technology (JAMSTEC); Igor Polyakov, IARC; and Sergey Priamikov, Arctic and Arctic Research Institute (AARI), St. Petersburg, Russia, and other Participants of the International Arctic Buoy Programme (IABP, http://iabp.apl.washington.edu/). This project is coordinated with the NOAA/SEARCH project Monitoring Ice Mass Balance in the Western Arctic Ocean, managed by J. A. Richter-Menge at the Cold Regions Research and Engineering Laboratory.

Rationale:

Dramatic changes in Arctic climate have been noted during the past two decades. Observations from the International Arctic Buoy Programme (IABP) have played a significant role in the detection of this change. For example, using IABP data, Walsh et al. (1996) showed that sea level pressure (SLP) has decreased; Rigor et al. (2000) showed that surface air temperature (SAT) has increased; and in concert, the circulation of sea ice and the ocean have changed so as to flow less clockwise (Steele and Boyd 1998; Kwok 2000; and Rigor et al. 2002). In addition to studies of Arctic climate and climate change, observations from the IABP are also used to validate satellites, for forcing, validation and assimilation into numerical climate models, and for forecasting weather and ice conditions.

Monitoring the Eurasian Basin is important since this is the center of many of the changes in Arctic climate. For example, the decrease in SLP noted by Walsh et al. (1996), the warming in SAT noted by Rigor et al. (2000), and the thinning of Arctic sea ice noted by Rothrock et al. (1999) are most significant in this area. One could ask, did the increase in SAT act to thin sea ice, or did the thinner sea ice allow more heat to flow from the ocean to warm the atmosphere? It has been hypothesized that the dynamic thinning of sea ice driven by the changes in atmospheric circulation causes the increasing trends in SAT (e.g., Rigor et al. 2002).

Brief Statement Of Objective:

We propose to deploy enhanced buoys in the Eurasian Basin of the Arctic Ocean (Fig. 1), which will monitor the mass balance of sea ice to verify this hypothesis, and complement the observations collected by the IABP. Establishing a record of climate-induced changes in the thickness of the sea ice cover is essential to understanding the role of the sea ice cover in the global climate system and to the application of the sea ice cover as an early indicator of global climate change. As explained in the recent report on the Study of Environmental Arctic Change (SEARCH) Workshop on Large-Scale Atmosphere/Cryosphere Observations (Overland et al. 2002), buoys within the IABP network can play an important role in monitoring changes in ice mass balance by enhancing their measurement system.

The observational array of the IABP is maintained by the 20 Institutions from 10 different countries (http://iabp.apl.washington.edu/Participants.htm), supports the World Climate Research Programme (WCRP), the World Meteorological Organization (WMO) World Weather Watch (WWW) Programme. The IABP is an Action Group of the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM).

<u>FY 2004 PROGRESS</u>

1. Ice Mass Balance Buoy Deployments (Fig. 2)
    1.1. Oden Deployment – September 2004

Collaborated with the Swedish Meteorological and Hydrological Institute (SMHI) to deploy 1 Ice Mass Balance buoy (Buoy # 25753) during their Arctic Coring Expedition.

1.2. North Pole Environmental Observatory (NPEO, http://psc.apl.washington.edu/northpole/) Deploymenbts – April 2004

Collaborated with the PSC North Pole Environmental Observatory (NPEO) project to deploy 4 Ice Mass Balance buoys (Buoy #s: 7100, 7105, 25752, and 25753). Two of these buoys were deployed in Automated Drifting Stations (ADS) collocated with an ocean buoy from JAMSTEC (Buoy # JCAD-8), and with a suite of buoys at the NPEO.

1.3. IOS/JAMSTEC/WHOI CCG Deployment – September 2003 and 2004

Collaborated with the Institute of Ocean Sciences researchers to deploy 3 Ice Mass Balance buoys north of the Beaufort Sea from the CCGS Louis St. Laurent in September 2003 and 2004. These buoys were collocated in ADS' with ocean buoys from JAMSTEC and the Woods Hole Oceanographic Institute (WHOI).

1.4. IARC/AARI NABOS Deployment – September 2003

Collaborated with the International Arctic Research Center (IARC) Nansen and Amundsen Basins Observational Systems (NABOS) researchers to deploy a CRREL Ice Mass Balance buoy north of the Laptev Sea (80.1N 146.1E) from the Kapitan Dranitsin in September 2003. This buoy was deployed in a 300km array with meteorological buoys of the IABP.

2. Data Collection and Analysis

We have begun processing and quality control of the data collected from the Ice Mass Balance buoys. For operational use, these data are available in near real-time through the Global Telecommunications System. For research, the data from the Ice Mass Balance buoys are included in the databases of the IABP, which are analyzed at the PSC, and are available through the IABP web server (http://iabp.apl.washington.edu/). The data are also archived at the World Data Center for Glaciology.

Data from the IABP have been used in over 450 publications. Please see http://iabp.apl.washington.edu/Citations/ for list citations through 2003.

Figures

Figure 1. This map shows the area of the Eurasian Arctic Ocean where we plan to deploy enhanced buoys from the North Pole Environmental Observatory. This map also shows the mean field of ice motion analyzed from buoy data (red arrows); the residence time of sea ice (gray lines, these contours show the number of years that ice along each line would take to drift across the Arctic Ocean and exit through Fram Strait); the boundary between ice that will exit Fram Strait or recirculate in the Beaufort Gyre (dashed gray line); and the Transpolar Drift Stream (thick blue arrow).

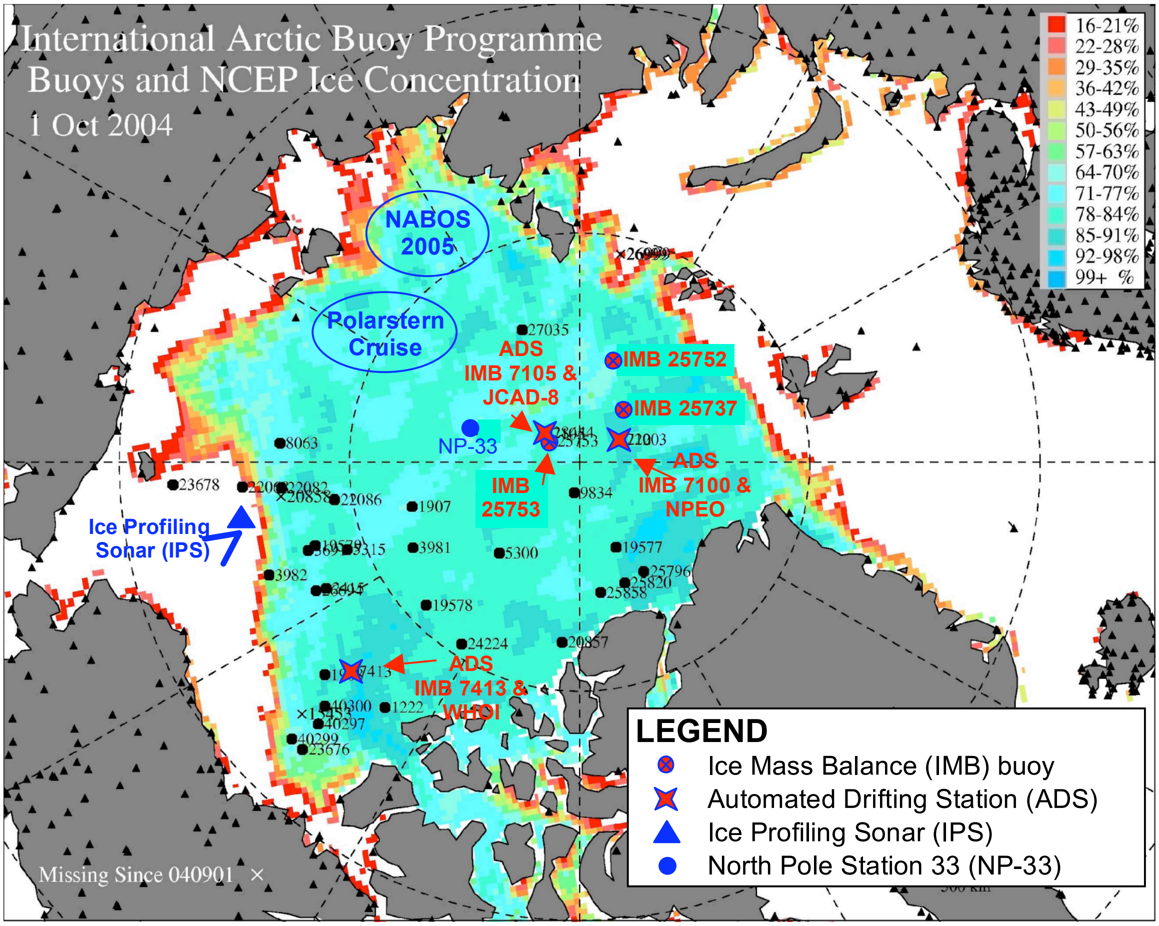


Figure 2. Current locations of Ice Mass Balance (IMB) buoys. The locations of "solo" IMB buoys are marked by red dots, while IMB buoys deployed in Automated Drifting Station (ADS) are marked by red stars. The planned deployment areas of IMB buoys from the NABOS and Polarstern cruises during the summer of 2005 are shown by blue ovals. The positions of other IABP buoys (black dots) and the Ice Profiling Sonar (IPS, blue triangle) are also shown. The sea ice concentration data were obtained from the National Center for Environmental Prediction.

3.32a. High-Resolution Ocean And Atmosphere PCO_2 Time-Series Measurements

by Christopher Sabine

PROJECT SUMMARY

General Overview

The fossil fuel carbon sources and the growth of atmospheric CO_2 are reasonably well known based on economic reconstructions and atmospheric monitoring (Prentice et al. 2001). A number of complementary, albeit indirect, means have been proposed for partitioning the long-term net carbon sink between ocean and land reservoirs, producing generally similar results for the global net ocean uptake of ~2 Pg C yr^{-1}. These include global ^{13}C budgets for CO_2 (Quay et al. 1992; Tans et al. 1993; Heimann and Maier Reimer 1996; Quay et al. 2003), data based estimates of anthropogenic CO_2 inventories in the ocean (Gruber et al. 1996, Sabine et al. 1999, Sabine et al. 2002, Sabine et al. 2004), ocean forward and inverse models (Sarmiento et al. 2001; Gloor et al. 2003), and combined use of atmospheric oxygen and CO_2 records (Keeling and Shertz 1992, Keeling et al. 1996). Given the significant uncertainties that are associated with each of these indirect methods, it is imperative to document the time evolution of surface ocean CO_2 concentrations over time.

The regional air-sea flux patterns are less well known, with significant disagreement among atmospheric inversions, ocean surface pCO_2 flux estimates and ocean numerical models (Takahashi et al. 2002; Gurney et al. 2002). The limited number of long-term ocean time series stations show significant biogeochemical variability from sub-diurnal to decadal timescales. Changes in large-scale ocean-atmosphere patterns such as El Niño/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the North Atlantic Oscillation (NAO) appear to drive much of the inter-annual variability, and this variability is expressed on regional (several hundred-to-thousands of kilometers) rather than basin-to-global scales. Large inter-annual variability in the partial pressure of surface water CO_2 (pCO_2) and CO_2 fluxes in the Equatorial Pacific are well documented (e.g., Feely et al. 2002). The general magnitude and mechanisms of mid-latitude variability signals are less clear (LeQuere et al. 2000; 2003), but significant year to year variability is evident in the subtropical Bermuda Atlantic Time-Series Station (BATS) and Hawaii Ocean Time-Series (HOT). Large annual and interannual variation in pCO_2 is also observed in sub-polar regions, but is very poorly characterized due to a lack of data.

The slower, decadal time-scale ocean responses (e.g., changes in nutrient stocks and community structure) are not as well characterized as the interannual response, though there is tantalizing evidence for large-scale biogeochemical regime shifts (or perhaps secular trends) (Karl 1999) and changes in nutrient distributions (Emerson et al. 2001). Distinguishing a human-induced, climate-change signal from natural decadal variability on this time-scale is often singularly difficult, particularly given the relatively short duration of most oceanographic data records. But model projections suggest that anthropogenic impacts are accelerating and may become more evident in the near future.

A wide variety of mechanisms have been identified that could conceivably alter ocean carbon uptake, but in many cases even the sign of the biogeochemical response, let alone the quantitative magnitude, is uncertain (Denman et al. 1996; Doney and Sarmiento 1999). Potential effects include:

- decreased calcification from lower pH and CO_3^{-2} ion concentrations resulting from anthropogenic CO_2 uptake (Kleypas et al. 1999; Riesebell et al. 2000, Feely et al. 2004);
- decreased vertical nutrient supply and in some regions enhanced, effective-surface-layer light supply leading to often opposing regional changes in primary productivity (Bopp et al. 2001);
- alterations in the spatial patterns and community composition of marine biomes due to changes in stratification (Boyd and Doney 2002);

- modifications in dust deposition and iron fertilization affecting the high nitrate-low chlorophyll (HNLC) regions such as the Southern Ocean and possibly subtropical nitrogen fixation;
- decoupling of carbon and macronutrient cycling because of shifts in the elemental stochiometry of surface export and differential subsurface remineralization.

Accounting for such hypotheses in future climate projections is presently problematic given our current understanding and modeling tools (Doney 1999; Falkowski et al. 2000).

Time-series records are key to characterizing the natural variability and secular trends in the ocean carbon cycle and for determining the physical and biological mechanisms controlling the system. Year-to-year variations in physics (e.g., upwelling, winter mixing, lateral advection), bulk biological production, and ecological shifts (e.g., community structure) can drive significant changes in surface pCO_2 (and thus air-sea flux) and surface nutrient fields. The biological and chemical responses to natural perturbations (e.g., ENSO, dust deposition events) are particularly important with regard to evaluating potential climate responses and for evaluating the prognostic models used in future climate projections.

Ship-based time-series measurements are impractical for routinely measuring variability over intervals from a week to a month; they cannot be made during storms or high-sea conditions, and they are too expensive for remote locations. Instrumental advances over the past 15 years have led to autonomous moorings capable of sampling properties of chemical, biological, and physical interest with resolution as good as a minute and a duty cycle of a year or more (e.g., Chavez et al. 1999; Dickey 2003). This work has provided a growing body of evidence that episodic phenomena are extremely important causes of variability in CO_2 and related biogeochemical properties and processes. Time-series moorings are essential for documenting the temporal evolution of the ocean carbon system. These moorings, particularly when co-located with shipboard time-series programs, are also invaluable for developing and testing new chemical and biological techniques and autonomous sensors as well as serving as focal points for process studies.

Since December 1996, the Monterey Bay Aquarium Research Institute (MBARI) has maintained bio-optical and chemical instrumentation on two moorings in the Equatorial Pacific in collaboration with NOAA/PMEL, with support from the NOAA/OACES (then NOAA/OGP's Global Carbon Cycle program) and NASA/SIMBIOS programs. In 2002 NOAA's Global Carbon Cycle (GCC) program funded a proposal to begin transferring the pCO_2 system technology developed at MBARI to PMEL with the idea that PMEL would begin developing a pCO_2 mooring network. While MBARI maintained its original two systems at 0°, 155°W and 2°S, 170°W, PMEL built and deployed two new systems at 0°, 125°W and 0°, 140°W. In 2003, PMEL was funded by the GCC to also deploy a system at the Hawaii Ocean Time-series site, bringing the total number of systems to five. In 2004, the moored CO_2 program was picked up by the Office of Climate Observations as part of the ocean observing system for climate. The moored pCO_2 network is still in its infancy, but hopes to expand into a global network of surface ocean and atmospheric CO_2 observations that will make a substantial contribution to the production of CO_2 flux maps for the global oceans. The long-term goal is to populate the network of OCEAN Sustained Interdisciplinary Timeseries Environment observation System (OceanSITES; http://www.oceansites.org/OceanSITES/) so that CO_2 fluxes will become a standard part of the global flux mooring network. This effort has been endorsed by the OceanSITES science team. Additional information about the moored pCO_2 program can be found at: http://www.pmel.noaa.gov/co2/moorings/.

Relationship to NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate: The moored pCO_2 program directly addresses key element 8) Ocean Carbon Monitoring Network, as outlined in the Program Plan, but also provides a value added component to elements 4) Tropical Moored Buoy Network and 6) Ocean Reference Stations. Within the Ocean Carbon Monitoring Network element, there are three major related components: repeat hydrographic sections, underway surface pCO_2 measurements, and moored pCO_2 measurements. Each component addresses a different timescale of variability. The moored pCO_2 program is designed to assess the short-term variability that cannot be accomplished with shipboard measurements. Obtaining long-term records of these high-resolution measurements allows a full integration of the short-term variability into the longer-term records obtained from the other elements of the CO_2 program. In particular, the moored pCO_2 data will directly contribute to the production of regional CO_2 flux maps and is being examined as a component of a new breed of data assimilation models that include estimates of carbon distributions and fluxes.

National and International Linkages:
Recognizing the need to develop an international framework for carbon research, various working groups of programs like the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Programme (IHDP), the Intergovernmental Oceanographic Commission (IOC), and the Scientific Committee on Oceanic Research (SCOR) have worked together to develop research strategies for global carbon cycle studies. The two primary international ocean carbon research programs are the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) and the Surface Ocean Lower Atmosphere (SOLAS) programs. Both programs strongly recommend carbon time-series measurements. These programs are very supportive of NOAA's efforts to develop a global pCO_2 mooring network and a number of international colleagues have expressed interest in working with us to include carbon measurements on their moorings. Because ocean carbon is relevant to so many international programs, IOC, SCOR and the Global Carbon Project (GCP) have co-sponsored the International Ocean Carbon Coordination Project. The goals of the project are to gather information about on-going and planned ocean carbon research and observation activities, to identify gaps and duplications in ocean carbon observations, to produce recommendations that optimize resources for international ocean carbon observations and the potential scientific benefits of a coordinated observation program, and to promote the integration of ocean carbon observations with appropriate atmospheric and/or terrestrial carbon activities. In addition to providing direct links to the international research programs, our involvement in the IOCCP provides a link to the global observing programs such as GOOS, OOPC, GCOS, and JCOMM.

The primary large-scale ocean carbon program within the United States is the Ocean Carbon and Climate Change Program (OCCC). Carbon time-series measurements play a key role in the OCCC plan. The emphasis during the first part of OCCC Phase 1 is on maintaining existing open ocean Northern Hemisphere subtropical and equatorial stations and establishing new sites or augmenting ongoing time-series in the sub-polar North Atlantic or North Pacific Oceans as the groundwork for follow-on process studies. Pilot Southern Ocean time-series will be established toward the middle/end of OCCC Phase 1 as a prelude to a major Southern Ocean process study during Phase 2. The NOAA moored pCO_2 network is a critical component for meeting these national plans. In addition, the moored pCO_2 program is being coordinated with the overall NOAA and national carbon strategies through the Carbon Cycle Steering Team and is governed by the COSP Ten Climate Monitoring Principals.

<u>FY 2004 PROGRESS</u>

Background:
Since December 1996, MBARI has collaborated with PMEL to maintain pCO_2 sensors that were developed by MBARI on two TAO moorings in the equatorial Pacific at 155°W, 0° and 170°W, 2°S. During 2003, PMEL engineers worked with the MBARI group to take a similar MBARI designed pCO_2 system for a drifting buoy and modified it to work as a buoy based system. One major modification was the addition of a NOAA/CMDL certified standard gas that would allow the system to recalibrate autonomously. Four TAO buoys were also modified to house the new systems. The new buoy and pCO_2 systems were designed to allow any single component of the system to be easily exchanged, even on a deployed buoy if necessary. These new systems and buoys, which are built and maintained by PMEL, were deployed in September 2003 at 125°W, 0° and 140°W, 0°. In 2004, this program was officially transferred to the Office of Climate Observations (OCO). Also in 2004, a proposal to place a moored pCO_2 system on the new MOSEAN mooring to be deployed north of Honolulu at the Hawaii Ocean

Time-series site was funded by the OCO bringing the total number of system locations to five (Figure 1).

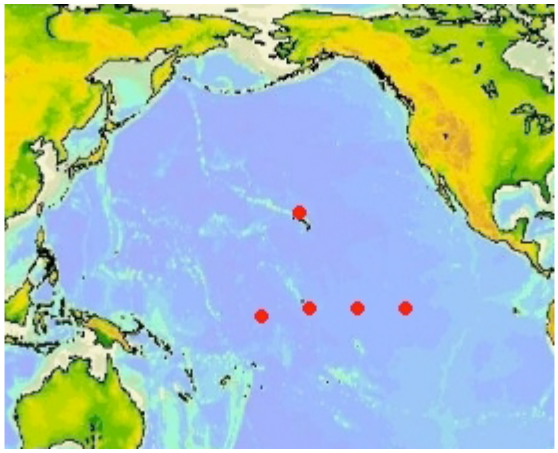


Figure 1. Map of moored pCO_2 systems currently deployed at part of this program.

This report summarizes the FY04 work from all of these programs.

Instrument/Platform Acquisitions and Number of Deployments:

Three new pCO_2 systems were built at PMEL during the year. Two systems were used to replace the recovered systems at 140°W, 0° and 125°W, 0°. The other system was built for the MOSEAN buoy. Systems at all four equatorial sites were replaced at least once during the year. The deployment at HOT was the only new deployment location for the year.

- 155°W, 0° - MBARI OASIS system swap in October 2003, internally recording instrument deployed in June 2004
- 170°W, 2°S – recovery and re-deployment of MBARI OASIS system in October 2003 and July 2004
- 125°W, 0° - recovery and re-deployment of PMEL pCO_2 system in May and battery and antenna replacement September 2004.
- 140°W, 0° - recovery and re-deployment of PMEL pCO_2 systems in May and Sep 2004.
- 158°W, 22.5°N – A PMEL pCO_2 system was deployed in MOSEAN Buoy at HOT in August 2004.

Problems and Improvements:

Vandalism has been a problem for the MBARI systems at 155°W and 170°W. The system deployed at 170°W in June 2003 was lost when the tower was ripped off the buoy. The MBARI system deployed at 155°W in October 2003 was also lost when the tower was removed. There was a time card problem at 170°W during the October 2003 deployment. This problem prevented the transmission of data back via satellite, but the data were still stored in the internal memory of the system and are being recovered now. Due to a shortage of systems resulting from the two tower losses, the MBARI system deployed at 155°W in June 2004 was only internally recording and did not have an Argos transmitter. The system at 170°W deployed in June 2004 stopped working after 6 weeks. With the latest revisit it was discovered that the battery cables had been severed and the batteries were dead.

FY04 was the first full field season for the PMEL pCO_2 moored systems. With each deployment and recovery, lessons were learned and improvements were made to the system. One difficulty that was experienced was the ability to verify the proper operation and accuracy of the moored pCO_2 systems before deployment. To resolve this problem, we designed a simple flow through container for the pCO_2 systems on the deck of the NOAA ship *Ka'imimoana* that is flushed with the same water being fed to the underway pCO_2 system being maintained by our group on this ship. The moored systems can then be turned on at the start of the cruise and compared with the underway data until they are set up in the buoy. Figure 2 provides an example comparison of the shipboard underway system and the moored system prior to deployment at 140°W. These data have shown that the moored systems are in good agreement with the underway data.

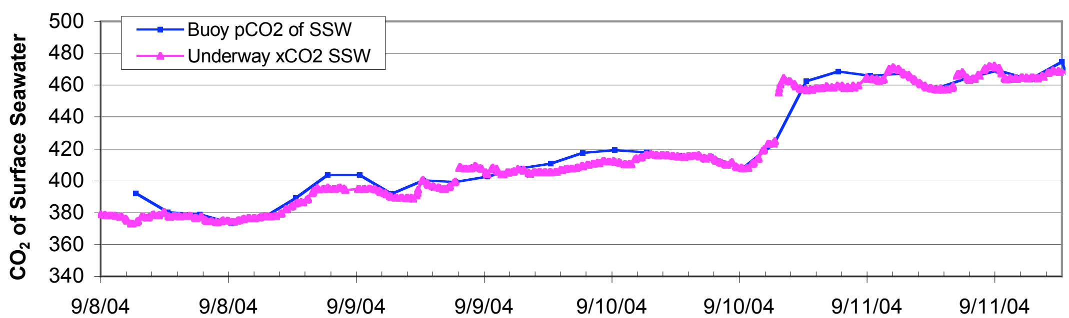


Figure 2. Underway (pink triangles) and moored (blue squares) pCO_2 system data recorded aboard the NOAA Ship *Ka'imimoana* along 140°W. Note that the moored pCO_2 system was mounted in a container on the deck of the ship with water from the underway system flowing through.

The software was also upgraded this year so that data collected immediately after the buoy deployment can be compared with the underway system to verify the proper functioning of the system and system accuracy. During the first few hours of deployment, the system collects data at faster intervals than its normal sample mode of every three hours. The shipboard operator can then call the buoy via satellite shortly after deployment to download the initial data collected to verify that everything is working properly before leaving the site (Fig. 3).

During the first deployments on the equator at 125°W and 140°W in 2003, the calibration gas regulators were not able to maintain a steady gas flow over the entire deployment period and the systems ran out of standard gas resulting in the loss of some data. Several changes were made to prevent this from happening in the future. First, fixed flow restrictors were installed into the regulators. Unlike the standard adjustable gas regulators, the flow restrictors are not susceptible to the buoy vibrations. We also modified the software to detect when the standard gas runs out so it knows to not attempt another recalibration of the instrument. Finally, the data stream was modified to collect the raw data from the detector in addition to the pCO_2 values based on the internal instrument calibrations. In the event that there is any problem with bad calibrations, the raw detector values can be used to recalculate final pCO_2 values using independently determined calibration factors.

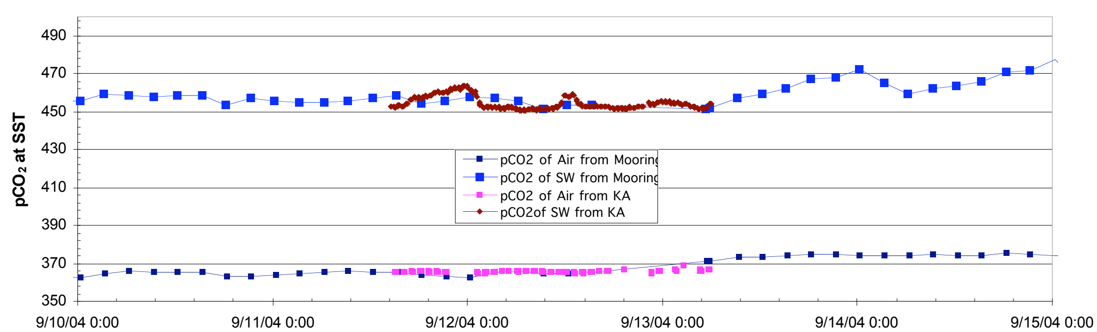


Figure 3. plot of moored pCO_2 values in surface seawater (large blue squares) and marine air (small purple squares) collected from the TAO buoy at 140°W, 0° and underway pCO_2 values (air=pink squares; water=brown triangles) while the ship was within 1° of the mooring. The moored pCO_2 system was serviced late in the day on 9/12/04. Note the continuity of the data before and after servicing.

Several mechanical obstacles were also overcome. In response to a recurrent valve leakage problem, the manufacture agreed to alter their design. The iridium modem was upgraded to a more robust model. The antennas were recently discovered to have a design flaw which causes cracks and allows saltwater to enter antenna. A redesign is being negotiated with the manufacturer. The equilibrators were initially made of low grade copper. After the first deployment, about 8 months, the bottom of copper legs partially eroded away. New equilibrators were built using a 70-30 copper-nickel alloy and were deployed in September 2004.

A problem was also encountered with the first MOSEAN deployment this year. As the Woods Hole Buoy Team was deploying the mooring, it flipped upside down and remained in this position for about an hour as the rest of the buoy cable and instrumentation was deployed. Once the full system was deployed, the weight of the cable and instrumentation righted the mooring, but our system had already run through at least three sampling cycles with the air intake approximately 1.5 meters underwater. Once upright, the pCO_2 was still operating and communicating, but it became immediately apparent that something in the pCO_2 system was not right. The suspected cause of malfunction was that the system had drawn water in through the air intake. This system will be replaced in November 2004 and we are exploring options for preventing this failure in the future.

Measurements and Data:
The MBARI systems measure the air-sea difference in pCO_2 at 3-hour intervals and had approximately a 50% return for FY04. At 155°W the data for the first half of the fiscal year were lost when the tower was removed. The data from the second half were only recorded internally and are in the process of being retrieved now. The data from 170°W in the first half of the year were recorded internally despite the fact that the satellite transmissions malfunctioned, but the data from the second half of the year were lost when

the battery cable was severed. MBARI is currently processing the data that was recovered from these two sites.

The PMEL moored pCO_2 system collects CO_2 and O_2 data from the marine boundary air and surface seawater. The systems are programmed to run every three hours and transmit a summary file each day. For the past year, 99% of the summary files were received from systems on the equator at 125°W and 140°W. Because the systems ran out of standard gas prematurely on the first deployment, some of the data were not properly calibrated but otherwise the systems mechanically functioned properly throughout the deployment. Since the second deployment in May of 2004, the data return for the systems at 125°W and 140°W has been 100% with no serious mechanical failures. See Figure 4 for representative data from 125°W and 140°W.

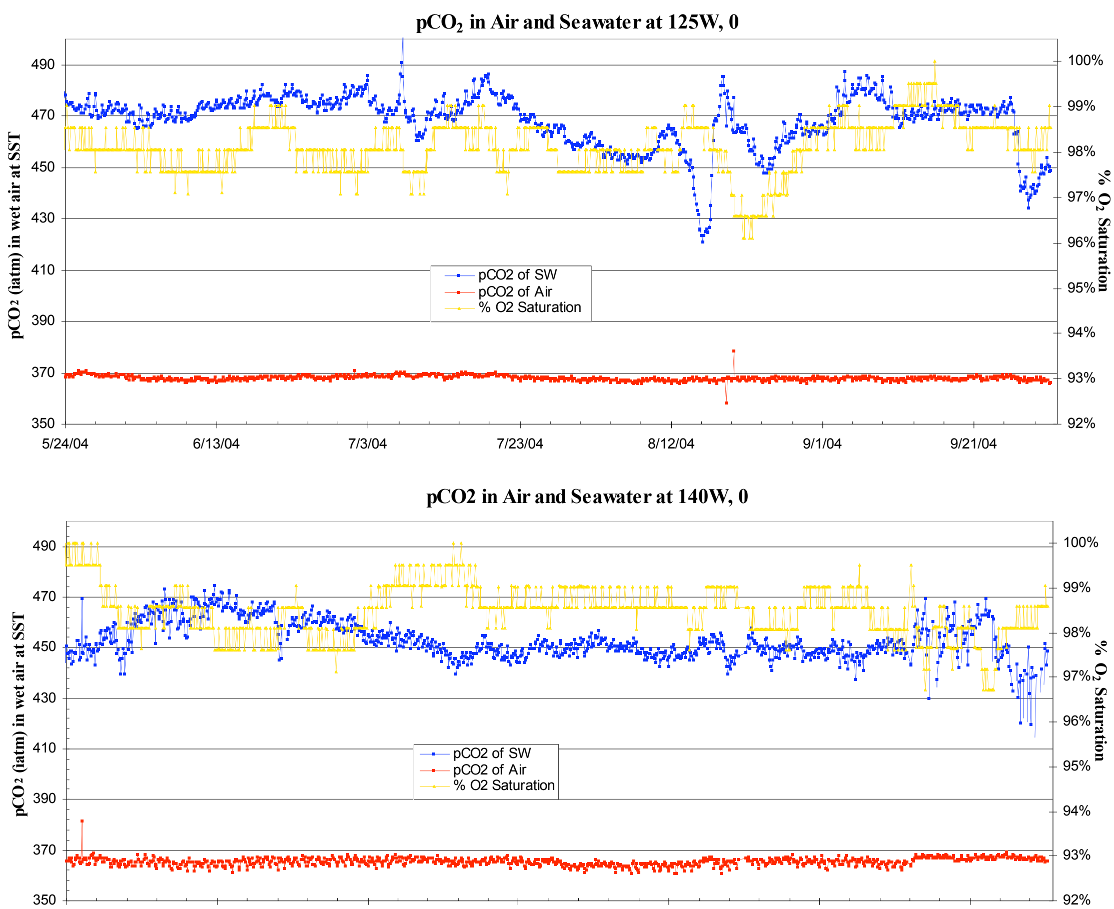


Figure 4. Surface seawater (blue) and marine air (red) pCO_2 values at 125°W, 0° (top) and 140°W, 0° (bottom) collected from the latest deployments of the systems. Gold values are the percent saturation of oxygen in surface water.

In addition to the moored pCO_2 data collected as part of this project, MBARI has been collecting nutrient and chlorophyll measurements on the TAO cruises. One person participates on each cruise and analyzes samples from the shipboard uncontaminated seawater supply and from CTD casts performed in-between buoy maintenance. These data have proven to be very helpful at interpreting the buoy based measurements and ultimately trying to examine the mechanisms controlling the observed variability in pCO_2.

Currently all the PMEL summary files are processed and graphed on a website that is updated daily [http://www.pmel.noaa.gov/co2/moorings/eq_pco2/eq_pco2.htm]. The data are currently stored at PMEL and are available from Christopher Sabine at PMEL. The MBARI data are available from Francisco Chavez at MBARI. Plans are now being put in place to archive the final calibrated data at the Carbon Dioxide Information Analysis Center (CDIAC) and the National Oceanographic Data Center (NODC) on a yearly basis.

Logistical Considerations:
The pCO_2 systems are mounted in buoys that are deployed from a ship. Currently all of our deployments are in conjunction with another project that is covering the buoy deployment and maintenance costs and has already allocated ship time. The pCO_2 systems are typically sent out on a cruise and are set up and deployed by a member of the scientific party as an ancillary task. This arrangement requires about 4 hours for setup and then approximately 10 additional man hours during the cruise. With our current configuration, the deployments do require a brief buoy visit with small boat to adjust the equilibrator to the correct depth. The nutrient and chlorophyll measurements require a person to be aboard each cruise to process samples.

3.33a. ***Document Ocean Carbon Sources and Sinks:***
Initial Steps Towards a Global Surface Water pCO_2 Observing System, and Underway CO_2 measurements on the NOAA ships *Ka'imimoana* and *Ron Brown* and RVIB *Palmer* and *Explorer of the Seas*

by Rik Wanninkhof, Richard A. Feely
with Nicholas R. Bates, Frank Millero, Taro Takahashi, and Steven Cook

PROJECT SUMMARY

Understanding the global carbon cycle and the determination of the regional sources and sinks of carbon are of critical importance to international policy decision making, as well as for forecasting long term climate trends. Projections of long-term global climate change are closely linked to assumptions about feedback effects between the atmosphere, the land, and the ocean. To understand how carbon is cycled through the global climate system, ocean measurements are of utmost importance. In this effort NOAA is outfitting research and commercial vessels with automated carbon dioxide sampling equipment to analyze the seasonal variability in carbon exchange between the ocean and atmosphere. This task is coordinated at the national level with the U.S. Global Carbon Cycle Science program and its subcommittee on Ocean Carbon and Climate Change (OCCC). To date it has benefited from the International Ocean Carbon Coordination Project (IOCCP) for international coordination exercises. The IOCCP is a joint endeavor of the SCOR/IOC CO_2 panel and the IGBP-IHDP-WCRP Global Carbon Project. Formal ocean basin ties are now being formed in the Atlantic through a Memorandum of Understanding with the European Union project Carbo-Oceans. Pacific collaboration is established through the PICES working group 13.

Documenting carbon sources and sinks relies critically on other efforts undertaken by the Climate Observations and Services Program, COSP including implementation of the ship lines, and moored and drifting arrays. The surface water pCO_2 programs support climate services by providing knowledge and quantification of climate forcing of the radiatively important gas, carbon dioxide. The near-term focus is on completion of the Northern Hemisphere ocean carbon observing system to assist in determining carbon dioxide sources and sinks over the coterminous United States in partnership with the atmospheric CO_2 observing system.

Two separate proposals have been joined into the underway pCO_2 observing program on volunteer observing ships (VOS) and research ships. It is a partnership of AOML, AOML/GOOS, PMEL, LDEO of Columbia University, RSMAS of the University of Miami, and the Bermuda Biological Station for Research (BBSR). Data from the project is being served from three websites that are linked and accessible from each.

1. http://www.aoml.noaa.gov/ocd/gcc
2. http://www.pmel.noaa.gov/co2/uwpco2/
3. http://www.ldeo.columbia.edu/res/pi/CO2/

All work follows established principles of monitoring climate forcing gases and biogeochemical cycles.

FY 2004 PROGRESS

Acquisitions, deployments and data return:

The pCO_2 observations from research ships and VOS have been performed on a routine basis on:

- NOAA ship *Ka'imimoana*: 8 cruises servicing the TAO mooring in the Equatorial Pacific
- NOAA ship *Ron Brown*: 15 cruises in Atlantic and Eastern Equatorial Pacific
- RVIB *Palmer*: 8 cruises in the Southern Ocean and Arctic, including a trans Pacific transit, between May 2003 and July 2004
- Royal Caribbean cruise line *Explorer of the Seas*: 48 cruises in the Caribbean Seas
- *Skogafoss* between Iceland and Boston (since December 2003)
- *Brown* (3 cruises since March 2004)

The cruise schedule of the research ships was similar to the previous year. The tracks for which data are posted for calendar year 2003 are shown in Figure 1. Data return from the ship was over 90%; the minimal data loss that did occur was due to instrument malfunction. Accurate records of malfunction are being kept such that we can get a better appreciation when systems need to be refurbished and to improve weak links. Although the systems are fully automated, all systems except that of the *Skogafoss* have a person on board for periodic checks. The *Skogafoss* operations have been problematic because of intermittent failures of the pumped waste water system that automatically shuts the system down to avoid flooding of the bilges.

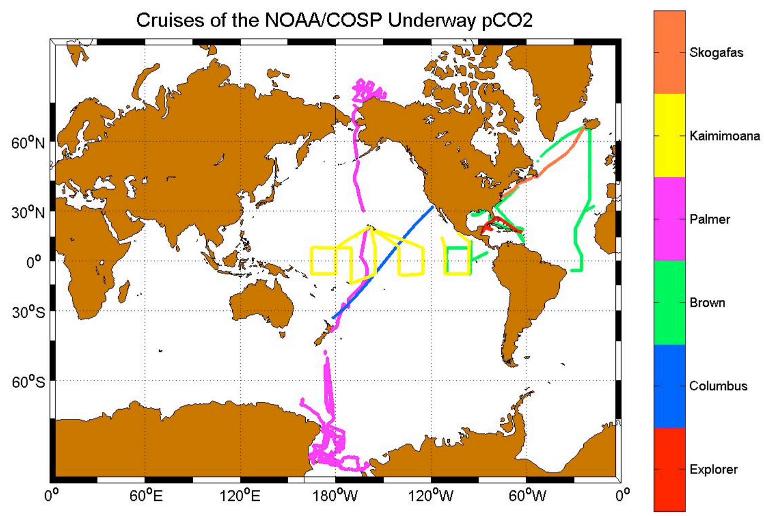


Figure 1. Lines occupied by the ships. The *Skogafoss* and *Columbus Waikato* tracks are monthly repeat occupations. The *Explorer of the Seas* are weekly occupations. The other tracks are one-time occupations during calendar year 2003.

A major component of the VOS pCO_2 work revolved around designing, building and testing the second generation of underway pCO_2 systems for ships of opportunity. A contractor at the University of Bergen built twelve systems with extensive input from the NOAA/COSP sponsored partners. Four of the systems are being purchased by the participants of this project. The others are going to groups throughout the world. The systems were intercompared against each other in Bergen in September 2004 with agreement between systems being better than 0.5 ppm; well within our performance standard of 1 ppm. Through close interaction of VOS group members with the builder, Craig Neill, we greatly facilitated the production and improvement of these systems. System parts were purchased by the VOS group members and credited towards instrument costs. The first generation systems that we currently have installed on VOS will be retrofitted to be fully compatible with the new systems.

In addition to our long-term underway pCO_2 measurements on the *Ka'imimoana*, we have successfully installed a new underway pCO_2 system on the *Columbus Waikato* this year for transits between the west coast of the United States, New Zealand, and Australia (Fig. 2). This research is done in collaboration with Drs. Paul Quay of the University of Washington and Bronte Tilbrook of the CSIRO in Hobart, Australia. In addition to supporting our underway pCO_2 measurements, they are also collecting samples for carbon isotope measurements (Quay) and DIC and nutrients (Tilbrook). For this reason, we have combined resources to place ship riders on each of the cruises. They maintain the underway systems and collect the discrete samples.

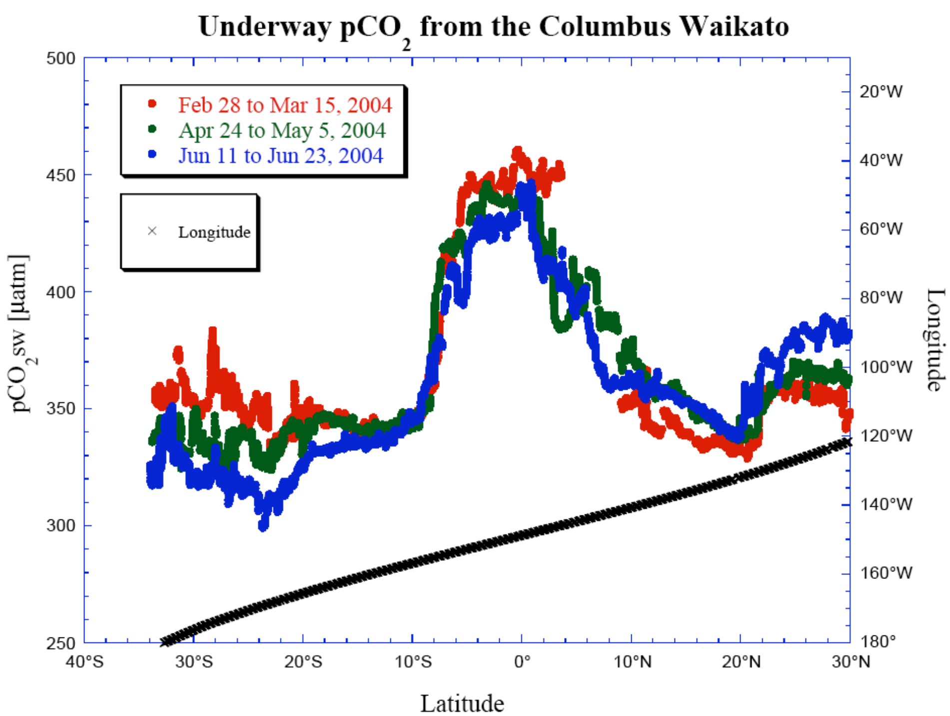


Figure 2. Surface water pCO_2 measurements from the first three transects of the *Columbus Waikato* across the Pacific Ocean from Long Beach CA to New Zealand.

The efforts of the NOAA VOS pCO_2 group thus have met the important monitoring principle of uniform instrumentation with a quantifiable accuracy. The first units were delivered in the summer of 2003, within a year of receipt of program funding. In FY04 two VOS ships were outfitted (the *Skogafoss* and the *Columbus Waikato*). The installation of the MV *Oleander* began at the end of the performance period.

NSF operates the RV *Gould* for the long-term study of ecological and biogeochemical changes in the Drake Passage and Antarctic Peninsula areas. Surface water pCO_2 has been measured by Colm Sweeney under a NSF funding in order to document the seasonal and interannual variability. These field data have been quality-controlled and processed at LDEO as a part of the VOS/NOAA program. Approximately 154,000 pCO_2 measurements have been finalized as described in the Progress Report Section for LDEO (Appendix 1, attached at the end of this report).

Data management and dissemination:
An important part of the VOS effort is to disseminate quality controlled data to the community at large in an expedient fashion. The LDEO group, in close interaction with the data acquisition groups, oversees shipboard quality control so that the quality of data is monitored as closely as possible to real time. This close coupling of the data acquisition with data processing/evaluation and interpretation will guarantee high quality field observation data. The LDEO group also coordinates submission of the collated data to the underway pCO_2 data center for community access. They participate in data interpretation with the data acquisition groups. This will facilitate discussions about data quality and insure that the observationalists will be engaged deeply in the interpretation processes.

Data obtained from the research ships are currently served from the institution responsible for the measurement. Although this component was not explicitly listed in the LDEO data management effort for the VOS proposal, the data from the research ships are currently being ingested by the LDEO group for their first annual release.

Data will be released to the internationally sanctioned data centers, NODC and CDIAC. CDIAC has just implemented a Live Access Server (LAS) for the data with funding from a companion effort. The LAS at http://cdiac3.ornl.gov/underway/servlets/dataset will be populated in the coming year. Investigators, and the oceanographic community use the data extensively. These data is also used for national and international assessments such as the IPCC.

Good progress has been made to post the pCO_2 data on the web sites. A listing of current updates is provided below. A major change has been the formatting. Based on a meeting in Japan sponsored by IOCCP in January 2004, an international standard of data formatting was adapted for this program. AOML and PMEL have reformatted most of their data to this format.

Latest updates (as of September 2004):

http://www.aoml.noaa.gov/ocd/gcc

Brown:	November 2003
Explorer:	August 2004
Skogafoss:	None

http://www.pmel.noaa.gov/co2/uwpco2/

Ka'imimoana:	August 2004
Columbus Waikato:	August 2004

http://www.ldeo.columbia.edu/res/pi/CO2/

Palmer	July 2004

In several instances, several years of data have been posted over the last year.

Problems:

The major problems encountered were late receipt of funds from NOAA, in particular for our academic colleagues, which slowed down the work schedule. Access to ships has been difficult at times, which has slowed installation, particularly for the MV *Oleander*. In this instance, installation of the pCO_2 system on the MV *Oleander* in the port of Newark became very problematic. At the request of the owners and captain, installation has shifted to Hamilton, Bermuda. Routine data downloads from the *Skogafoss* have sometimes not occurred in port because personnel of the GOOS/SEAS group, who are partners in this effort, were not available. Part of the problems is associated with lack of personnel resources which were requested as an "Add task" in FY-04 but were not funded. In FY-05 we have included the needed personnel in the budgeted request.

Systems on the ships have worked very well, except for the *Skogafoss*. The *Skogafoss* is the only ship without a person on board for periodic checks. The *Skogafoss* operations have been problematic because of intermittent failures of the pumped waste water system that automatically shuts the system down to avoid flooding of the bilges. Never-the-less data has been obtained on about half the transects (Fig. 3). On the *Oleander*, the equilibrator will free drain into a waste reservoir, which in turn will be drained by a new pump back into the seawater line downstream of the tap off to the pCO_2 system. A new equilibrator was placed on the *Explorer of the Seas*. We have determined that a ship rider is required to attend the underway system on the *Columbus Waikato* because of the difficulties associated with the language differences between the scientists and the crew. We found that by working with scientists from the University of Washington, CSIRO in Hobart and the University of Southern California we can accomplish that task, provided we continue our subcontract with the University of Southern California.

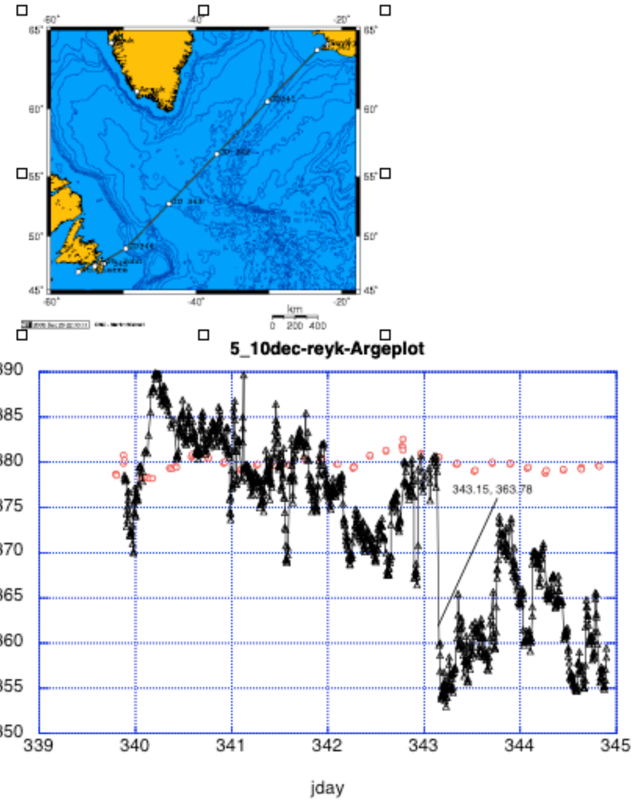


Figure 3. pCO_2 data from the *Skogafoss* from December 5-10, 2003. The top panel shows the cruise track with open circles demarking each day. The bottom panel shows the mole fraction of CO_2 (XCO_2) in air (red circles) and water (black line).

Project costs:

Anticipated- Anticipated data costs include data reduction, dissemination, interpretation, and data archiving. Anticipated instrument costs include design, purchase, installation and maintenance.

Unanticipated- Unanticipated costs included higher maintenance costs, instrument development costs, and personnel costs to repair and maintain systems.

Logistical considerations- Work on the research ships proceeded as planned. The *Brown* was used for the several coastal cruises in the NE Atlantic that will provide important baseline considerations for the anticipated coastal carbon program.

Although the RVIB *Palmer* has been operating primarily in the Southern Oceans, she was assigned to operate in the Arctic waters during 2003. Thus, the *Palmer* sailed from the Southern Ocean to the Arctic Sea across the equatorial Pacific and Bering Sea, and returned to the Southern Ocean. This has given us a tremendous pCO_2 data set: two N-S trans-Pacific profiles in a single year at no extra cost to the CO_2 project. This demonstrates that extensive observations can be made over the global oceans at virtually no extra cost.

Research highlights;

1. The NOAA Ocean and Atmosphere Research laboratories in collaboration with Joint Institute partners and other academic investigators sponsored through OAR/OGP have been on the forefront of field investigations on how gases exchange between the ocean and atmosphere. One of the goals is to investigate the patterns of sequestration of carbon dioxide. On average the ocean takes about 1/3 of the carbon dioxide produced by fossil fuel burning but with significant regional, seasonal, and interannual variability. As part of this project two large multidisciplinary field studies were performed in 1998 and 2001 in the north Atlantic and Equatorial Pacific on NOAA ship *Ronald Brown*. In 2004 the

results of these studies and that of other investigations of air-sea gas transfer were compiled in a special section of the Journal of Geophysical Research. Four major papers of importance from this volume are included in the reference section.

The papers describe the physical, chemical and biological conditions that affect the air sea exchange of CO_2 in the equatorial Pacific Ocean. The research provided new parameterizations of the air-sea exchange of CO_2 in the equatorial Pacific and new estimates of CO_2 flux for the region based on these parameterizations. The combined effects of uncertainties in the gas transfer velocity and wind fields lead to average difference of 27% between the lowest and highest estimates of the CO_2 flux from the region. Although the gas exchange wind speed expressions varied greatly, the calculated fluxes were very similar because of both the narrow wind speed range encountered and the converging relationships near the mean observed wind speed of 6 m/s. The most recent CO_2 data suggests that a weak ENSO event is beginning in the Eastern Pacific (Fig. 4).

2. The pCO_2 measurements performed over the last two decades in the Equatorial Pacific, primarily by the investigators in this proposal, have shown a large shift in pCO_2 levels and CO_2 fluxes. The pCO_2 levels in the 80-ties increased more slowly than in the 90-ties with the change in trend occurring at the beginning of the 90-ties. This timing corresponds with a change in the Pacific Decadal Oscillation (PDO). It reinforces the hypothesis that natural climate reorganizations have a major effect on air-sea CO_2 fluxes. While studies by our group have clearly shown the large effect of the ENSO on the fluxes, including the last few months (Fig. 4), this is the first time the effect of the longer time scale oscillations on the oceanic carbon system have been demonstrated. Our latest results are utilized to document the decadal changes in the CO_2 fluxes from this important region.

3. It is widely recognized that robust methods to interpolate CO_2 measurements in time and space are needed to produce CO_2 flux maps from measurements along a line. Publications by Cosca et al. (2003) and Feely et al. (2004) for the Equatorial Pacific and Olsen et al. (2003) for the Caribbean Seas show how temperature can be utilized to produce regional flux maps. The algorithms are area specific but show a robust predictive capacity and provide a way to utilize remote sensing to produce flux maps with high spatial and temporal resolution. The data used to create the algorithms were obtained on the ships funded under this effort.

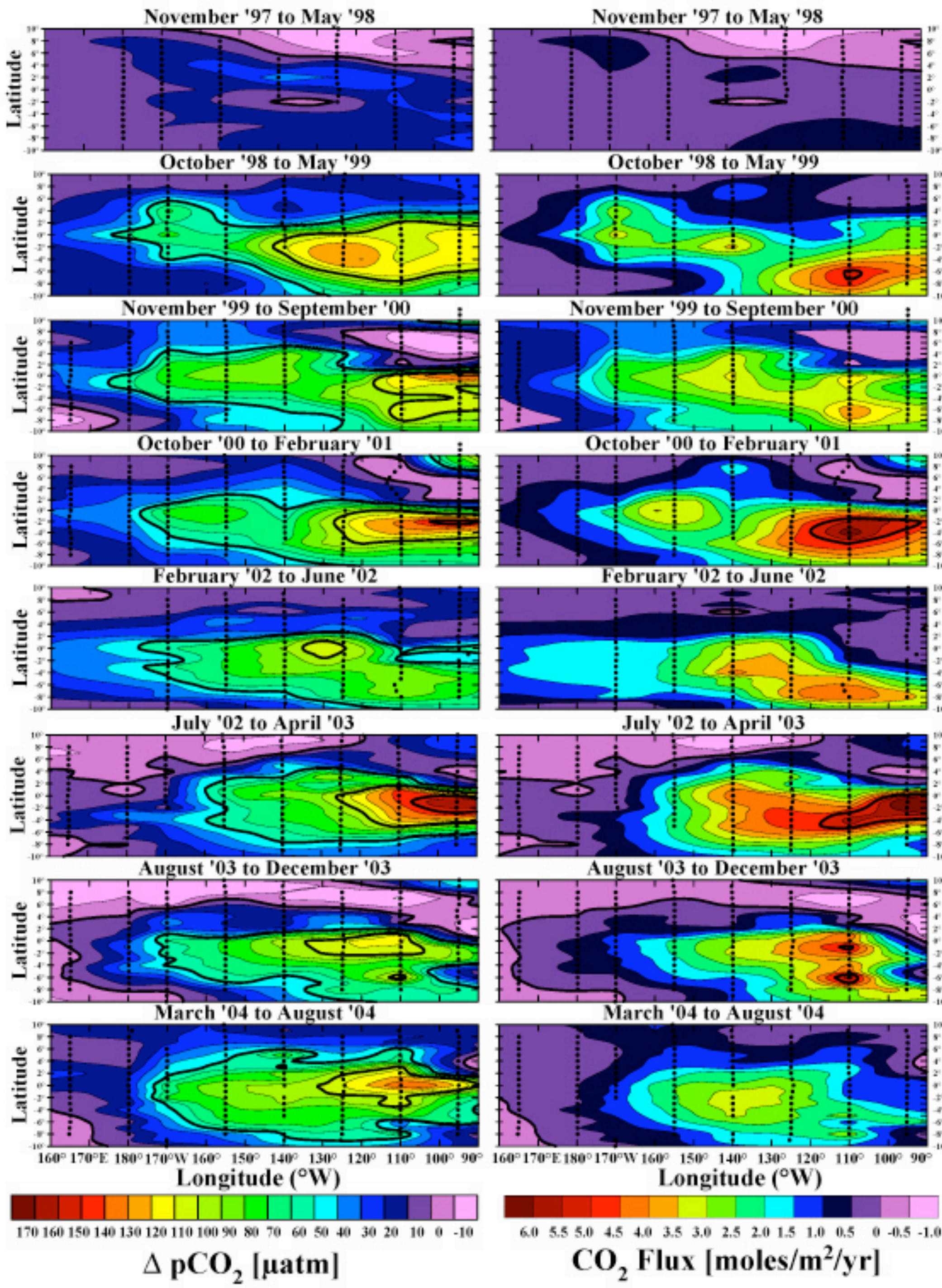


Figure 4. Time series of pCO_2 distributions (μatm) and CO_2 flux (mol/m^2/yr) between November 1997 and August 2004. Low CO_2 fluxes are observed during both the strong 1997-98 El Nino and the weak 2002-3 event.

The algorithms are area specific but show a robust predictive capacity and utilize remote sensing data to produce flux maps with high spatial and temporal resolution. The data used to create the algorithms were obtained on the ships funded under this effort. The efforts were continued with the Caribbean data from the *Sealand Express*. The algorithm developed for 2003 was very similar to the 2002 algorithm developed by Olsen et al. (2003) with an average offset of 1.5 μatm (that fortuitously is similar to the expected oceanic increase). Weekly flux maps were produced from this algorithm to estimate the regional flux in the area. The weekly flux maps are presented on: http://www.aoml.noaa.gov/ocd/gcc/salinity/explorer.html.

4. The decadal trends of surface water pCO_2 in 23 areas (about 5° x 5° on the average) in the tropical and North Pacific Ocean have been investigated by Takahashi using the observations made since the 1970's. In 19 areas that are located in the open North Pacific, the surface water pCO_2 values have been increasing at a rate similar to the mean atmospheric CO_2 increase of about 1.5 ppm/yr. Although surface waters are out of equilibrium with atmospheric CO_2 because of the seasonal swing of SST, biological production and deep-water upwelling, the ocean surface waters appear to take up CO_2 from the air keeping up with the atmospheric CO_2 increase. In contrast, in four areas located near and within the Bering and Okhotsk Seas, the surface water pCO_2 have been decreasing with time, in spite of the fact that surface water temperatures have been increasing. This may be attributed to an increase in photosynthesis in the high latitude northern North Pacific, that have been reported by Gregg et al. (2003) on the basis of remote-sensed ocean colors.

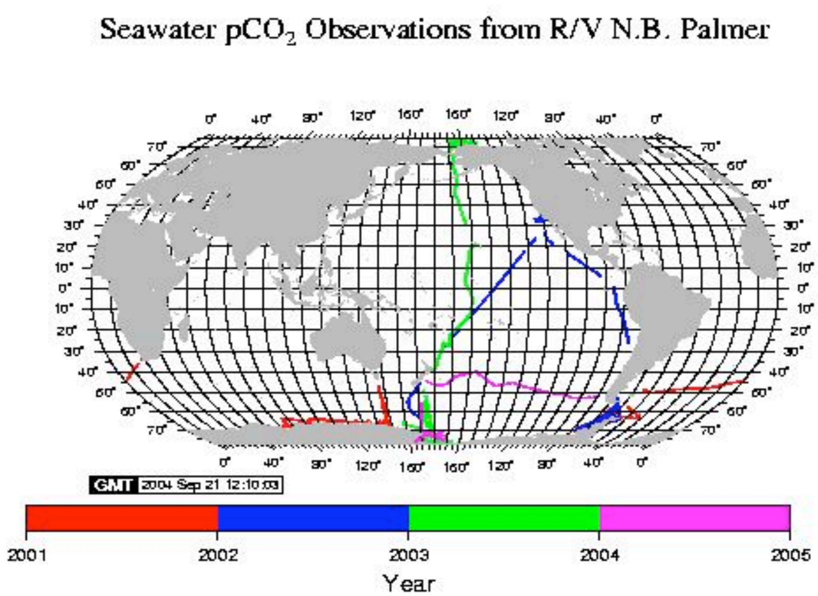


Figure A1 – Locations of the surface water pCO_2 measurements obtained aboard the RVIB Palmer in 2001 – 2004.

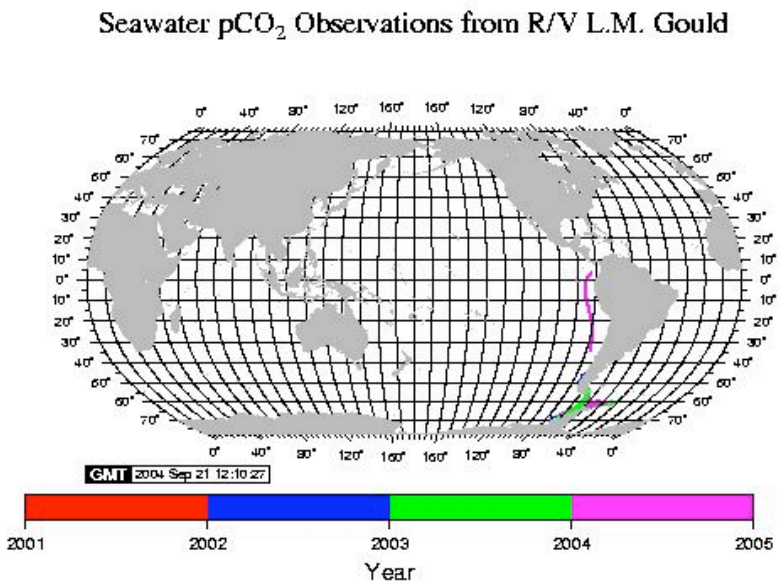


Figure A 2 – Locations of the surface water pCO_2 measurements obtained aboard the RV Gould in 2001 – 2004. The measurement program has been supported by NSF, and the data were obtained under the direction of Colm Sweeney. The data were processed under the VOS program.

3.34a. Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS)

Robert A. Weller and Albert J. Plueddemann

PROJECT SUMMARY

Overview:

The goal of this project is to maintain long-term surface moorings, known as Ocean Reference Stations (ORS), as part of the integrated ocean observing system. The scientific rational for these stations is to collect long time series of accurate observations of surface meteorology, air-sea fluxes, and upper ocean variability in regions of key interest to climate studies and to use those data to quantify air-sea exchanges of heat, freshwater, and momentum, to describe upper ocean variability and describe the local response to atmospheric forcing, to motivate and guide improvement to atmospheric, oceanic, and coupled models, to calibrate and guide improvement to remote sensing products and capabilities, and to provide an anchor point for the development of new, basin scale fields of the air-sea fluxes. Model, satellite, and climatological fields of surface meteorology and air-sea fluxes have large errors; high quality, in-situ time series are the essential data needed to improve our understanding of atmosphere-ocean coupling and to build more accurate global fields of air-sea fluxes.

Under this effort three sites are being maintained: the site at 20°S, 85°W under the stratus cloud deck off northern Chile (Stratus), the Northwest Tropical Atlantic Station (NTAS) at 15°N, 51°W, and a site north of Hawaii near the Hawaii Ocean Timeseries (HOT) site. The Hawaii WHOI reference station was established this year in cooperation with Dr. Roger Lukas of the University of Hawaii (funded by NSF) and is denoted WHOI-HOTS or WHOTS. After several years of support for mooring deployment and annual servicing under NOAA OGP, the Stratus and NTAS sites have transitioned to long-term Ocean Reference Stations. The Hawaii station is being done in collaboration with investigators that have made shipboard and moored observations in the HOTS region in recent years. In the management of the **Ocean Reference Stations** project, four tasks have been identified. First, there is the engineering, oversight, and data management (**Task I**), second, maintenance of the Stratus site (**Task II**), third, maintenance of the NTAS site (**Task III**), which is now covered under a grant to Plueddemann, but will in FY2005 shift to support as one of the operational ORS, and fourth, establishment of the Hawaii ORS (**Task IV**). Progress on each of the Tasks is reported in more detail below. Note that we also report on the **Northwest Tropical Atlantic Station for Flux Measurement (NTAS)** project here in order to be responsive to the request for evolution toward a single report for an element of the observing system.

Addressing NOAA's Program Plan:

This program directly addresses the sixth element of the Program Plan for Building a Sustained Ocean Observing System for Climate – Ocean Reference Stations. It works in synergy with many of the other elements (Global Surface Drifting Buoy Network, Global Ships of Opportunity, Argo Profiling Float Array, Satellites for Sea Surface Temperature, Sea Surface Height, and Surface Vector Winds) by providing high temporal resolution at fixed points to complement the Lagrangian or spatial sampling of the other elements. It is also an important element of assimilation efforts, as surface fluxes can be diagnosed from the ocean and provide a means to assess the models being used for assimilation.

Management in Cooperation with International Panels:

The Ocean Reference Stations project is managed in cooperation with the International Time Series Science Team (co-chaired by R. Weller), a joint planning effort that involves the climate, carbon, and other disciplinary communities interested in long time series and that reports to the Ocean Observations Panel for Climate (OOPC) and to the Partnership for Ocean Global Observations (POGO, an international consortium of directors of oceanographic institutions). The link to JCOMM observations is through the OOPC. The ORS project, and more generally the International Time Series Science Team, because of its importance to and emphasis on air-sea fluxes, has also reported to the WCRP Working Group on Numerical Experimentation (WGNE) to develop explicit links to the weather and climate modeling centers. An outcome of this is the SURFA project, where time series we collect are provided to Peter Gleckler at PCMDI for inclusion in the AMIP (Atmospheric Model Intercomparison Project). We are now participating in a new WCRP/CLIVAR oversight group on air-sea fluxes formed recently with Chris Fairall as the Chair. We have participated in planning for CLIVAR, for the Carbon Cycle Science Plan implementation, and for SOLAS, working to see that the Ocean Reference Sites develop to serve the needs of the research programs.

Responsible Institution:
The Woods Hole Oceanographic Institution is the responsible institution for all aspects of this project.

Websites:

WHOI's website:	http://www.whoi.edu
UOP Group's site:	http://uop.whoi.edu
Stratus Project site:	http://uop.whoi.edu/stratus
NTAS Project site:	http://uop.whoi.edu/ntas
WHOTS Project site:	http://uop.whoi.edu/hawaii

Partnerships:
Planning and implementation of the ORS includes a number of partnerships. The Hawaii site was equipped with ocean instrumentation through a National Science Foundation grant to Roger Lukas of the University of Hawaii. The Stratus site was chosen in collaboration with the Chilean Navy Hydrographic and Oceanographic Service (SHOA), and trips to the Stratus site have involved Chilean (SHOA, the University of Concepcion, and the University of Chile, Santiago) and Ecuadorian (Navy oceanographic office, INOCAR) participation. The Stratus site provided the focal point for the stratus component of the multi-agency cooperative EPIC 2001 field program and is included as a focal point for a CLIVAR VOCALS (VAMOS Ocean Cloud Atmosphere Land Study) process study in 2006 or 2007. The NTAS site may similarly provide a focal point for a field study (RICO) of tropical convection and clouds now under discussion by Chris Bretherton and Bjorn Stevens. Surface meteorological and air-sea flux data from our sites are made available to various national/international centers (NCEP in the U.S., ECMWF in Europe). There is strong synergy between our program and the National Science Foundation program on Ocean Observatories, and the NSF effort is looked to as the means to develop observatory hardware capable of extending the ORS to higher latitude sites of high scientific and operational climate interest.

Monitoring Principles:
The project is managed in accordance with the Ten Climate Monitoring Principals.

Task I Engineering, oversight and data:
<u>FY2004 PROGRESS</u>
Design of a new buoy for use at the Ocean Reference Stations was completed in FY2003, and the first complete buoy system was deployed in 2004. These new buoys replace the 15-20 year old hulls presently used which are degrading (corrosion of the welded aluminum) and are expensive to ship as they do not fit inside a sea container like the new hulls. Six new buoy hulls were slated for construction. The first of the new buoy hulls, tower tops, and cabling systems was utilized for the WHOTS project, deployed in August 2004. This represents an increase in the number of stations being supported from two last year to three this year. Preparation of the second system has been completed; it will be deployed at the Stratus site in December 2004. The third buoy system is presently being outfitted for deployment at the NTAS site in March 2005. The remaining three hulls have been constructed, and one of them is nearing completion as a ready-for-sea system. These systems will be completed and deployed as a part of the next annual servicing cycles for WHOTS, Stratus, and NTAS, respectively. Four new meteorological sensor systems to be used to support the three sites have been acquired. Two complete systems were integrated with the

new tower tops, tested, and deployed at the WHOTS site. The other two systems are being integrated into a sensor pool that will support Stratus, NTAS and WHOTS. Data acquisition and processing for all three sites continues on schedule.

Acquisitions: Six new buoy hulls have been fabricated and four new meteorological sensor systems were acquired. These assets are being used for Tasks II (Stratus), III (NTAS), and IV (WHOTS).

Data storage, Distribution, Access, Archiving: The oversight task coordinates the common data tasks for the three sites. Oceanographic (velocity, temperature, salinity) and surface meteorological data (wind speed and direction, air and sea surface temperature, rain, incoming shortwave and longwave, relative humidity, and barometric pressure) are processed and stored on disks attached to our workstations. Telemetered data are made available via an FTP server and a website with download capability. This website is in the process of being upgraded and re-organized. We also maintain a public access archive of Upper Ocean Processes Group data from mooring deployments.

Anticipated and unanticipated project costs: Deployment of the WHOTS Ocean Reference Station (WHOTS) in August 2004 represented a two-year acceleration relative to our initial proposal and budget for deployment in summer 2006. The additional cost of this work was handled through a Project Acceleration or "Add Task" to the FY2004 ORS budget in the amount of $376,700.

Problems: None significant.

Note that Deployments, Data Return, Measurements, Data Sharing, Logistical Considerations, Research Highlights, Publications, Conferences, Meetings, and Outreach are described under the individual Tasks II, III, and IV below.

Task II Stratus Site:

Stratus FY 2004 PROGRESS

The stratus surface mooring was deployed first under the previous grant (under the Pan American Climate Studies) in October 2000. It was recovered and redeployed from the NOAA Ship *Ronald H. Brown* in October 2001. This mooring was recovered using the *RV Melville* (Puerto Caldera, Costa Rica to Arica, Chile) in October 2002 and a new mooring deployed at the same site. In 2003, the mooring was recovered and redeployed by *RV Revelle,* sailing from Manta, Ecuador on November 10, 2003 and arriving in Arica, Chile on November 26, 2003. During that cruise we assisted the Ecuadorian Navy (INOCAR) with one of their surface moorings and also supported NOAA (PMEL and NDBC) technicians training Chilean Navy (SHOA) staff in deploying a DART (tsunami detection) buoy purchased by Chile from PMEL. At the Stratus site in-situ comparisons of the ship's and both buoys' meteorological sensors were carried out. During the deployments, hourly-averaged surface meteorology was available from the buoy in near real time via Service ARGOS and a WHOI ftp site. Data exchanges were made with ECMWF, NCEP and others to examine numerical weather prediction model performance and examine air-sea fluxes under the stratus clouds. The telemetered meteorological data are also available via the website maintained for this site (http://uop.whoi.edu/stratus). Internally recorded 1-minute meteorological data as well as the oceanographic data, which are only internally recorded, were downloaded from the recovered instrumentation. Data recovery was good (estimated to be 90%), post-calibrations are being done, and data files have been shared with colleagues. Preliminary cruise reports were filed with the State Department soon after the cruise; final documentation that goes to foreign observers and the State Department includes copies of the underway data and a final cruise report. Telemetry from the buoy presently deployed indicates that it is on station and both meteorological systems are functioning well.

Work this year included down-cruising hardware and instruments recovered in November 2003, doing post-calibrations, data processing, writing cruise and data reports, preparing the mooring and instrumentation for the next deployment, scheduled for December 2004 on board the NOAA ship *Ronald H. Brown*, starting in Arica, Chile and ending in Valparaiso, Chile, coordinating that cruise, and assembling, using, and making available a composite 3-year data set. Work on this task is on schedule.

Acquisitions: We did not acquire instruments. On our cruise on *RV Roger Revelle,* we deployed 45 surface drifters and 9 Argo floats (Fig II-1) to bolster sampling in the southeastern Pacific. On the *Ronald H. Brown* we will again do surface drifter and Argo float deployments.

Deployments: The Stratus site is visited once per year, in October through December, as required by battery and calibration life. The surface mooring there is recovered and a new mooring deployed. This year we will again service a DART mooring for the Chilean Navy (SHOA).

Measurements: On the buoy: air temperature, sea surface temperature, relative humidity, incoming shortwave and longwave radiation, wind speed and direction, rain rate, and barometric pressure. On the mooring line: concentrated in the upper 300m, temperature, salinity, and velocity. During the deployment, high data rate (up to 1 sample per minute) data are stored in each instrument. Hourly-averaged surface meteorology is telemetered via Service ARGOS; the telemetered data are stored at WHOI on a workstation. The telemetered data are available on the website (http://uop.whoi.edu/stratus) in near real time; it is also set up to be FTP'd to collaborators and those who request it. The internally recorded data goes through processing, has calibration information applied, and is subject to preliminary analyses before being made publicly available on our website. In the interim, preliminary versions are made available upon request.

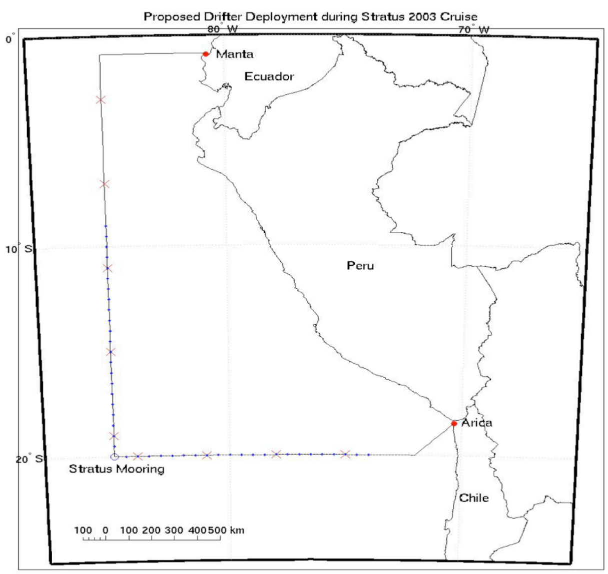


Figure II-1. Cruise track of RV Revelle in November 2003 during cruise to service the Stratus site. Forty-five surface drifters and nine Argo floats were deployed.

Data use and sharing: Hourly surface meteorological data are archived at WHOI, arriving within hours of when it was observed. These data are exchanged in near real time with ECMWF and NCEP; they in turn provide operational data at the grid point nearest the model. It is also shared with the Chilean Navy (SHOA). The same data are shared with CLIVAR investigators, especially modelers interested in the Stratus region, with VAMOS investigators in the U.S. and in South America. It is also sent to Peter Glecker at PCMDI for use in the SURFA project. These meteorological data are used to access the realism of operational atmospheric models in the stratus region. Once per minute, as well as hourly, surface meteorological time series are provided to the EPIC and VEPIC investigator communities (including Sandra Yuter, Chris Bretherton, Meghan Cronin). The surface meteorological data have been made available to the satellite community (including radiation – Langley, winds – Remote Sensing Systems and JPL, SST – Dick Reynolds, all variables – the SEAFLUX project). The oceanographic data are being used by Weller and a Postdoctoral Investigator at WHOI to investigate air-sea coupling and upper ocean variability under the stratus deck. In parallel it will be compared with ocean models (with Ragu Murtugudde, Univ. of Maryland).

Data archive: The initial archive is that maintained by the Upper Ocean Processes Group at WHOI, which maintains a public access server of their mooring data. We are working with the International Time Series Science Team to develop a number of sites that will maintain as many records of time series stations as can be collected to facilitate access to such data.

Costs: A great unknown continues to be the ports of call and length of the cruises to service the mooring; because of this labor costs for days at sea and shipping and agent's fees in foreign ports can exceed budgeted figures. We plan for roughly 16 days at sea. If we are assigned a longer cruise, the labor costs are beyond the budgeted amounts. Besides these costs we have been on track, with costs as laid out in the budget.

Problems: Availability of ship time continues to be a first order problem, as do the uncertainties of whether or not the ship costs will be covered by NOAA. Because of the high demand on Class 1 ships, we are often, as is the case this year, on a UNOLS vessel. There are difficulties of coordination between NOAA and UNOLS. There are also continuing issues about the UNOLS operators getting payment in a timely fashion. The performance of the RDI Acoustic Doppler Current Profilers deployed on this mooring has not been as expected. Range has been less than anticipated; additional Vector Measuring Current Meters (VMCMs) have been added to fill the gaps left by the RDI ADCP's short range. One of two units was returned to the manufacturer after failing to run for a full year; it was found to have excessive power consumption. In the last deployment we encountered problems for the first time with long-line fishing lines fouling some propeller current meters; we have deployed, and again will deploy in December 2004, additional single point acoustic current meters (Sontek and Aanderaa) to cope with this problem and assess the ability of these current meters to obtain data as good as that obtained by VMCMs.

Logistical considerations: We need to return every 12 months with about 2-4 weeks margin because of the lifetime of the batteries powering the instrumentation. Getting a Class 1 ship to the site every 12 months has become a major challenge,

We need 6 days on station with the ship at the mooring site. The work includes comprehensive comparison of ship and buoy meteorological sensors (Fig. II-2), which is critical to determining and demonstrating the accuracy of the moored sensors. The addition of air-sea flux studies at the Stratus site by Fairall (NOAA ETL) and others (such as cloud radar work by Yuter, Univ, of Washington) adds to the need, so that 10 days at site could be used. Every effort is made to work out of ports of call close to the site, but at times the ship opportunities that have been suggested have been as far as 20 steaming days away, which would cause a large increase in labor costs.

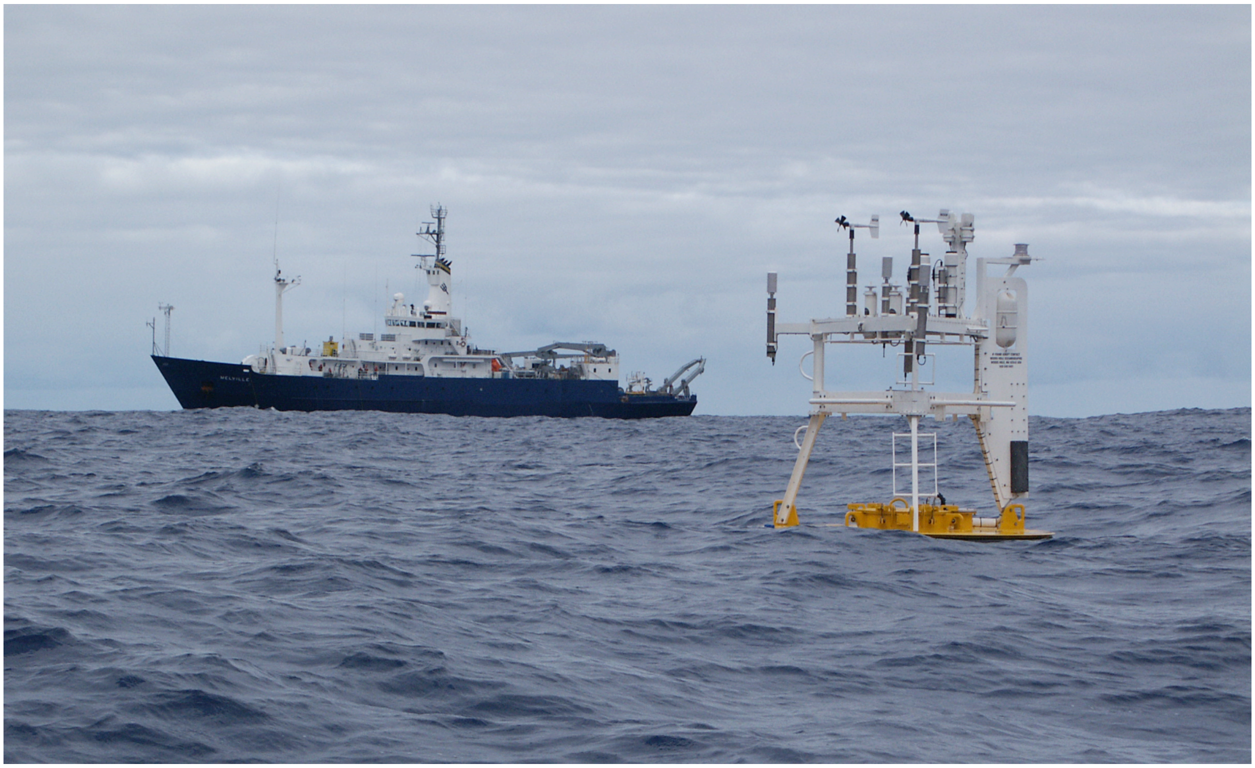


Figure II-2: The Stratus buoy with RV Melville in the background, taken during comparison of ship meteorological sensors (mounted on the tower on the bow) and buoy sensors.

Research highlights: The time series data from the buoy have provided the first accurate in-situ record of surface meteorology (Fig II-3) and air-sea fluxes (Fig II-4) under the stratus clouds, and there has been great interest in how the in-situ data compares to model and climatological data. Note that these figures provide documentation of significant biases in the reanalysis and climatological fields; the annual means are compared in Fig. II-5. Figure II-5 also points to greater year-to-year variability in the observations than in the model.

Another unique achievement of the Stratus mooring is the collection of the first record of upper ocean variability under the stratus clouds (Fig. II-6). Because these data have coincident surface forcing, work is underway to diagnose the local heat budget and assess the role of local air-sea interaction in maintaining the sea surface temperature under the stratus deck. Evidence of locally-wind driven flow to the southwest, off to the left of the wind, is apparent in the current

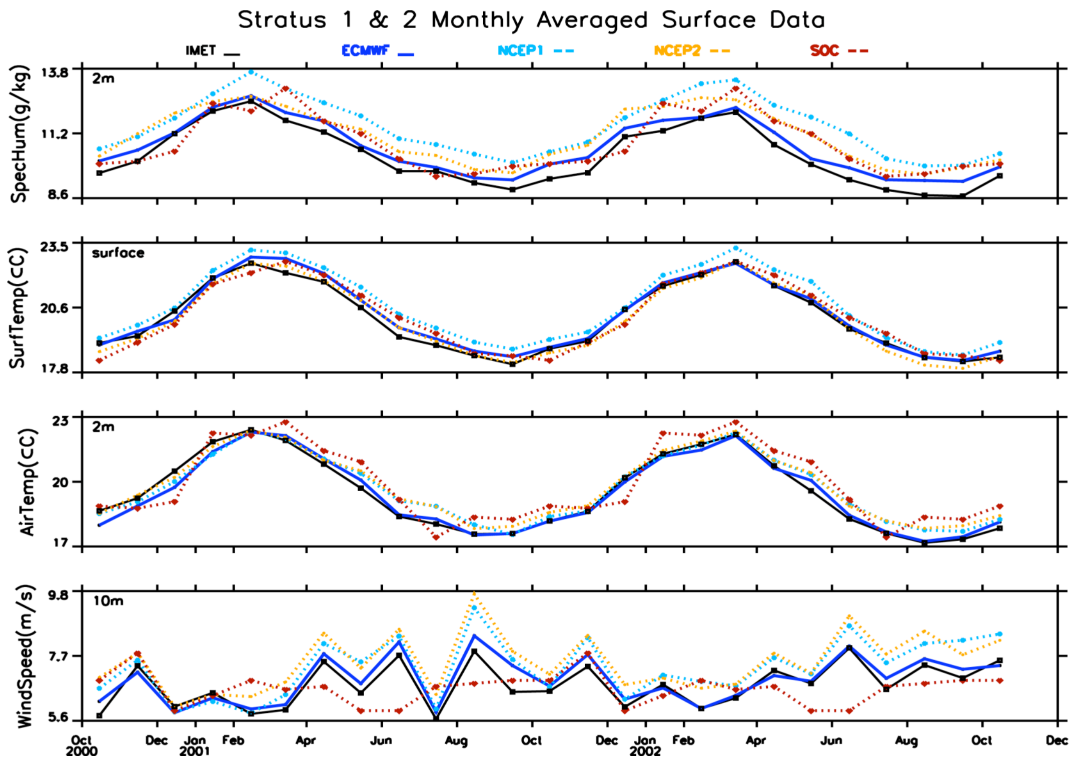


Figure II-3: Comparison of the first two years of stratus buoy meteorological data with atmospheric model reanalyses (ECMWF ERA-15, NCEP1, and NCEP2) and COADS climatologies.

Figure II-4 Comparison of the air-sea fluxes at the Stratus buoy for two years with reanalysis and climatological data as in Fig. II-2.

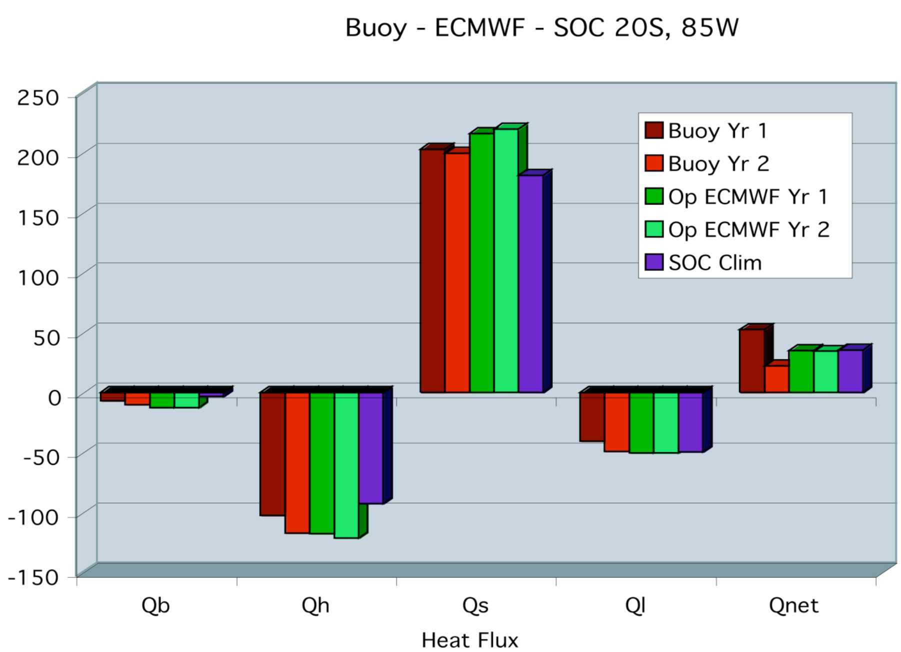


Figure II-5: Comparison of annual means of the heat flux components (sensible – Q_b, latent – Q_h, shortwave – Q_s, longwave – Q_l, and net heat – Q_{net}) for the first two years of data from the Stratus buoy with operational ECMWF model and SOC climatological heat fluxes.

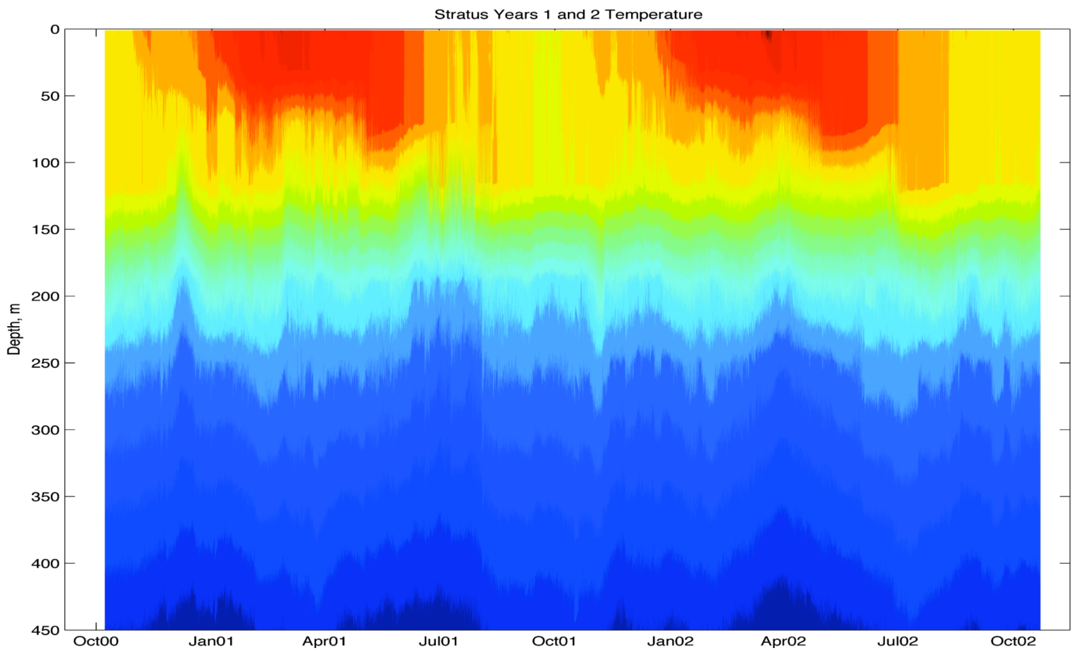


Figure II-6: Two years of temperature data from the upper 450 m at Stratus site.

meter data (Fig. II-7). Work is underway to quantify the extent to which this offshore flow carries cool water upwelled along the coast out under the stratus cloud deck. It has been found that local atmospheric heating of the ocean drives diurnal heating on low-wind days and a strong seasonal cycle, and also that another, non-one-dimensional process such as horizontal advection is needed to remove some of the heat from the atmosphere. We have just submitted a publication based on this work (Colbo and Weller, submitted – included in the Appendix.) The research community interested in stratus clouds, their impacts on radiation, and the processes that govern their formation have been very interested in the data. We have shared that data with the CLIVAR CPT (Climate Process Team) on cloud processes led by Chris Bretherton and participate in the steering team for that CPT. Our buoy data are being analyzed by several groups (Cronin at PMEL, Yuter, Bretherton, and Comstock at U. Washington, Nystuen at U. Washington Applied Physics Lab, and others) in the context of the EPIC program and the EPIC 2001 process study. Early results from EPIC 2001 are presented in Bretherton et al. (2004), which is included in the Appendix.

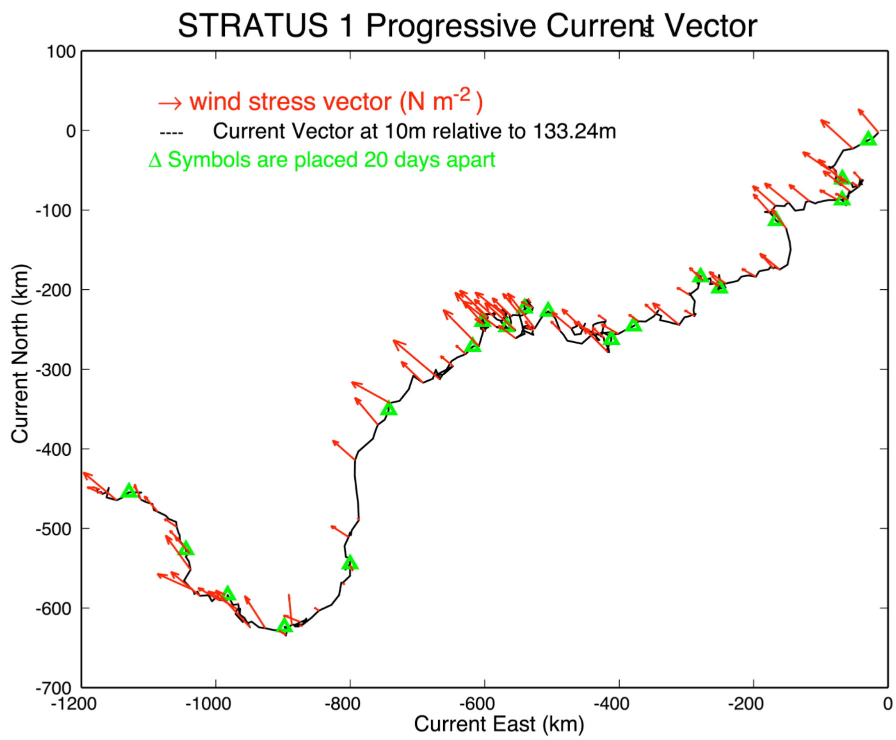


Figure II-7. The progressive vector diagram for the flow at 10 m relative to that at 133 m is plotted in black. Green triangles are spaced 20 days apart. Weekly-averaged wind stress vectors are shown as red arrows. The southeast Trades drive flow to the southwest in the upper ocean.

Task III NTAS Site:
The Ocean Reference Station grant will take over support for NTAS in 2005. At present NTAS is funded under its own grant, but managed by Al Plueddemann as an element of the Ocean Reference Station project. We thus include its report here.

The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant local air-sea interaction on seasonal to decadal time scales. The strategy is to maintain a meteorological measurement station at approximately 15° N, 51° W through successive (annual) turn-arounds of a surface mooring (Fig. III-1). Redundant meteorological systems measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

NTAS has two primary science objectives. First, to determine the air-sea fluxes of heat, moisture and momentum in the northwest tropical Atlantic using high-quality, in-situ meteorological measurements from a moored buoy. Second, to compare the in-situ fluxes to those available from operational models and satellites, identify the flux components with the largest discrepancies, and investigate the reasons for the discrepancies. An ancillary objective is to compute the local (one-dimensional) oceanic budgets of heat and momentum and determine the degree to which these budgets are locally balanced.

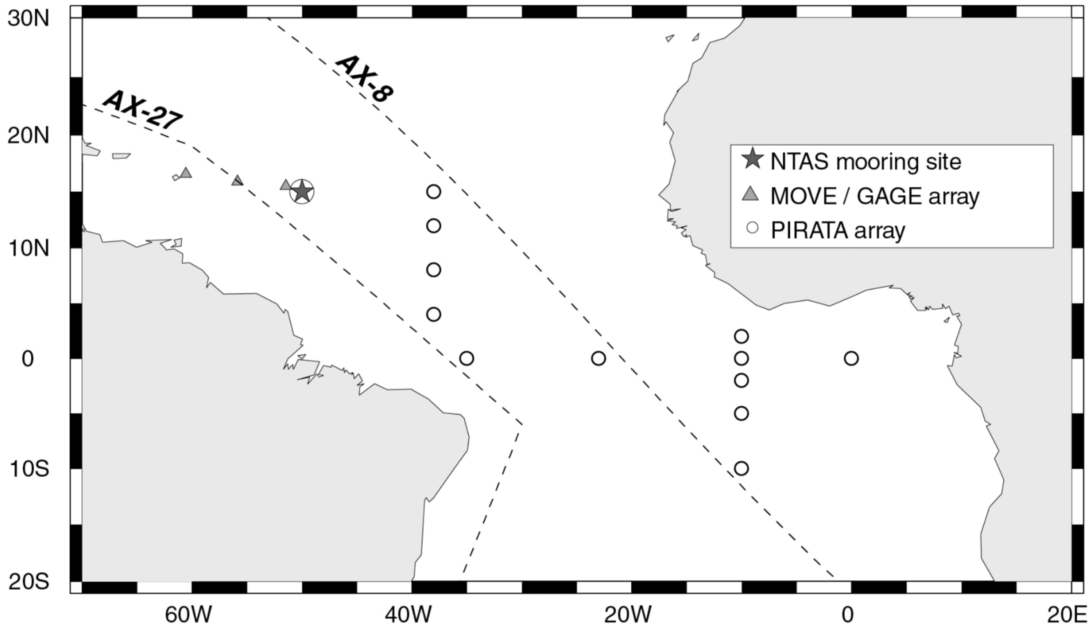


Figure III-1. Location of the NTAS site (circled star) relative to the GAGE/MOVE array (triangles) and the PIRATA array (circles). The approximate routes of XBT lines AX-8 and AX-27, along which surface flux observations are proposed, are shown as dashed lines.

This project addresses NOAA's Program Plan by maintaining an Ocean Reference Station providing high-quality surface meteorology and air-sea fluxes at a key site in the northwest tropical Atlantic. In conjunction with other elements of the Climate Observing System (e.g., volunteer observing ships) it is anticipated that the spatial scales over which the buoy data are applicable will be determined, leading to the development of improved surface flux fields for that region.

NTAS FY 2004 PROGRESS

Three Air-Sea Interaction Meteorology (ASIMET) systems were assembled and tested. Two systems, comprised of the best performing sensors, were mounted on a three-meter discus buoy in preparation for deployment. A mooring turn-around cruise was conducted on the NOAA Ship *Ronald H. Brown* in order to retrieve the existing mooring (NTAS-3, deployed 14° 50' N, 51° 01' W on 15 February 2003) and replace it with the new mooring (NTAS-4). The NTAS-3 mooring was recovered on 19 February 2004, and the NTAS-4 mooring was deployed at 14°44' N, 50°56' W on 21 February 2004. A 24-hour period immediately after deployment was dedicated to an intercomparison of the NTAS-4 ASIMET system and the shipboard meteorology. To ensure high-quality meteorological data, all NTAS-4 sensors were calibrated prior to deployment, and NTAS-3 sensors will be post-calibrated.

Data return from the ASIMET system on NTAS-3 was 100% for all sensors. NTAS-2 also had 100% data return. NTAS-1 had partial data return from AT, RH, SST and SSC sensors. However, the purposeful redundancy of the system meant that alternate sensors could be used in each case, and a complete record of NTAS-1 surface meteorology was obtained. The meteorological data are being used as the basis for air-sea flux computations using bulk formulas. Post-calibrated and quality controlled data from NTAS-1 and NTAS-2 are archived at WHOI and available on line from the UOP web site. Complete, but uncorrected data from NTAS-3, and 8 months of uncorrected data from NTAS-4 are also available on-line.

The project used 14 days of ship time on the *Ronald H. Brown* in FY2004. Logistical challenges and unanticipated project costs tend to revolve around ports, shipping and ship scheduling. For example, in 2002 the mooring service cruise was a very efficient 7-day round-trip out of Barbados, but we incurred substantial costs for port services and shipping relative to our budget, which was for a domestic port. For the 2003 cruise, shipping costs were reduced substantial because we were able to partially load and offload *Oceanus* in Woods Hole. However, the cruise duration (Barbados/Woods Hole rather than Barbados/Barbados) was many days longer than budgeted, and we effectively traded shipping costs for salary costs. In 2004 the situation was intermediate between the two. The cruise was on the *Ronald H. Brown* out of Charleston, SC, so the domestic shipping costs were in line with our budget. However, salaries for the cruise (Charleston/Barbados) and a return trip to Charleston to offload the ship were higher than budgeted.

NTAS Research highlights:

Figure III-2 shows the annual cycle at the NTAS site as depicted by selected meteorological variables averaged over 1 week on a 13-month time base. Spring (MAM) is characterized by SST increasing from its annual minimum and very low levels of precipitation. Summer (JJA) is characterized by steady northeast winds (towards 255°) at 6-8 m/s and continuing increases in SST. Episodic precipitation begins in late summer. Fall (SON) is characterized by reduced solar radiation, SST decreasing from its annual maximum, persistent precipitation, and variable winds. By mid winter (DFJ), solar radiation begins to increase, precipitation decreases, and winds become steadier. A distinct surface salinity minimum is observed in early winter of the first two years. Monthly averages show a clear tendency for strong precipitation to be associated with SST above 27°C, as is characteristic of the Inter-Tropical Convergence Zone.

A preliminary assessment of surface meteorology and fluxes for the NTAS site was made by comparing ASIMET data from the NTAS-1 buoy with numerical model products from ECMWF and NCEP. The ASIMET data were from the best performing sensors on the buoy, logged at 1 min intervals. The ECMWF data were from the surface meteorology and diagnostics variables of the operational forecast model for the grid point nearest the buoy (courtesy of Anton Beljaars). NCEP-1 fluxes were from the NCEP/NCAR Reanalysis-1 data set and the NCEP-2 fluxes were from the NCEP/DOE Reanalysis-2 data set. The SOC climatology is based on COADS ship reports from 1980-1993. The ASIMET (1 min) and ECMWF (1 hour) data were averaged over six hours to match the NCEP time base.

Initial comparisons of the NTAS 1 and 2 fluxes with gridded products (Fig. III-3) indicate a variety of issues for further investigation. The two-year mean net heat flux is significantly underestimated by the three models (mean differences are 4-5 times larger than the expected error of about 10 W/m^2 from the buoy data). For ECMWF and NCEP-1 this is due to overestimation of latent heat losses and underestimation of shortwave gains. NCEP-2 shows a dramatic improvement in shortwave flux relative to NCEP-1, but still has a large net heat flux error due to substantial overestimation of latent heat losses. As a result, the amplitude of the annual cycle and the timing of positive to negative heat flux transitions are poorly reproduced by the models. In addition, all three models indicate a negative two-year mean net heat flux, whereas the observed value is +40 W/m^2. Interestingly, the climatological net heat flux is a better match to the observations than any of the models.

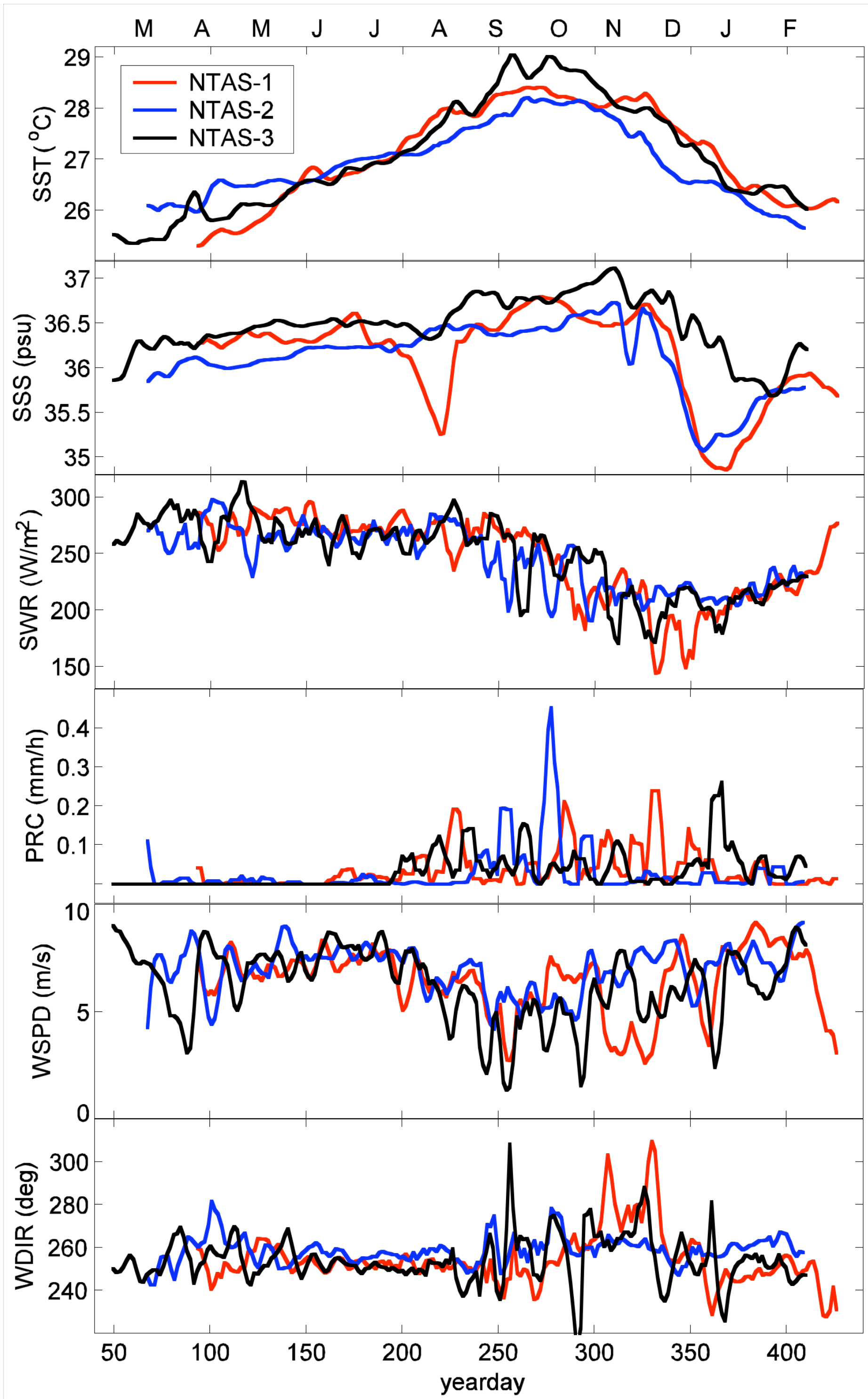


Figure III-2. The annual cycle of surface meteorology at the NTAS site as depicted by selected meteorological variables averaged over 1 week on a 13-month time base. Sea surface temperature (SST), sea surface salinity (SSS), downwelling shortwave radiation (SWR), precipitation rate (PRC), wind speed (WSPD) and wind direction (WDIR) are shown for deployments in 2001 (NTAS-1, red), 2002 (NTAS-2, blue) and 2003 (NTAS-3, black).

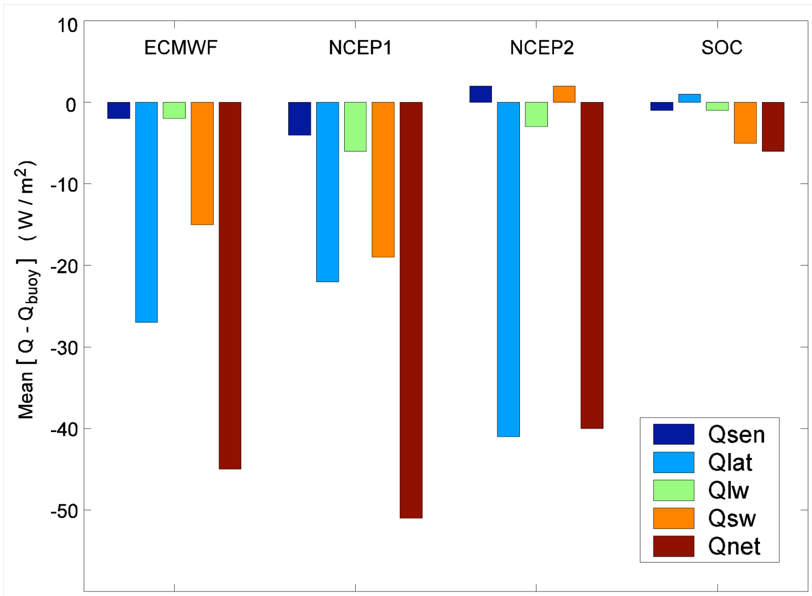


Figure III-3. Mean differences between heat flux components from gridded products and the NTAS buoy for a two-year period beginning in March 2001.

Task IV Hawaii Site:

This past year, with support from an add task put forward last year, we advanced the timetable for this element of the effort by two years. We had identified Hawaii as a third Ocean Reference Station site that would have high value to the integrated ocean observing system and also that could be maintained with tractable logistics and in cooperation with partners. These criteria were met, and we deployed a surface mooring equipped with two ASIMET meteorological systems at the HOT site, just north of Hawaii, in August 2004. The willing collaborators included Roger Lukas and colleagues at the University of Hawaii and Tom Dickey of the University of California, Santa Barbara. The logistics of cruises in and out of Hawaii were affordable and convenient, as some gear is now being staged there, reducing cost. Further, the heritage of prior observations at that site points to the value of an Ocean Reference Station there.

HAWAII FY2004 PROGRESS

Acquisition: None. Deployments, Data Return, Measurements, Data Storage, Data Use and Sharing, Data Archiving: The first deployment was successful and occurred in August 2004. Telemetered meteorological data is being made publicly available via the web. This data, plus that raw data to be recovered next year will be archived and made available.

Anticipated and Unanticipated Costs: Schedule has advanced two years, to deploy in the second year will require funds originally budgeted in the fourth year. These funds are listed below as an add task.

Problems and Logistical Considerations: Arranging for ship time each July is proving to be difficult; NOAA not having funds for the ship time continues to be a problem.

Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic

by Robert Weller

PROJECT SUMMARY

Central to present efforts to improve the predictability of climate is the need to understand the physics of how the atmosphere and ocean exchange heat, freshwater, and momentum and, in turn, to accurately represent that understanding in the models to be used to make predictions. At present, over much of the globe, our quantitative maps of these air-sea exchanges, derived either from ship reports, numerical model analyses or satellites, have errors that are large compared to the size of climatically significant signals. Observations made using the IMET technology on the Volunteer Observing Ships on long routes that span the ocean basins are essential to providing the accurate, in-situ observations needed to:

1) identify errors in existing climatological, model-based, and remotely-sensed surface meteorological and air-sea flux fields,
2) to provide the motivation for improvements to existing parameterizations and algorithms,
3) to provide the data needed to correct existing climatologies, and
4) to validate new model codes and remote sensing methods.

AutoIMET was developed by the Woods Hole Oceanographic Institution to meet the need for improved marine weather and climate forecasting. It is a wireless, climate quality, high time resolution system for making systematic upper ocean and atmospheric measurements. This interfaces to the NOAA SEAS 2000 (Shipboard Environmental (Data) Acquisition System) that automatically receives meteorological data (from the AutoIMET) and sends in automated one-hour satellite reports via Inmarsat C. This system will document heat uptake, transport, and release by the ocean as well as the air-sea exchange of water and the ocean's overturning circulation.

Note that descriptions, technical information and data from the several VOS being serviced are posted on the site: http://uop.whoi.edu/vos/. Data (plots) are available for all ship sets.

Data (numbers) are available via anonymous ftp for the last data set only:
ftp.whoi.edu/pub/users/fbahr/VOS. If data from previous times are desired please contact Frank Bahr at: fbahr@whoi.edu.

There is a link to the site: http://frodo.whoi.edu where there is detailed information on the AutoIMET and ASIMET modules. Instrument design questions can be addressed to Dave Hosom at: dhosom@whoi.edu.

Ship selection and interface to the NOAA SEAS system is via AOML. There is ongoing cooperation with Scripps via the CORCIII program as well as Southampton Oceanography Centre (SOC) of Southampton UK on Computer Flow Dynamics (CFD) for evaluation of the flow turbulence around the ship and its effect on the sensor placement. Some logistic support is provided by the Southern California Marine Institute on ship turnarounds. There is ongoing cooperation with the Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami on the Atlantic VOS program. There is also ongoing cooperation with many sensor manufacturers and the VOS people at the German Weather Service (Deutscher Wetter Dienst) in Hamburg Germany.

This project is managed in accordance with the Ten Climate Monitoring Principles.

FY 2004 PROGRESS

Ship selection for the Atlantic VOS was made late in 2003. AutoIMET systems were installed in June 2003 and December 2003 on the Pacific ships as part of a companion project.

SeaLand Express

- January 2004. A survey of the SeaLand Express was carried out by Frank Bahr in Newport News, VA in preparation for the AutoIMET system installation.

- March 2004. The AutoIMET system was installed on the SeaLand Express in Elizsabeth, NJ by Frank Bahr, Craig Marquette, Alan Gordon and Dave Hosom. The time in port was short and the weather was nasty. Steve Cook and Jim Farrington of NOAA helped with the AutoIMET installation and did the new NOAA SEAS 2000 installation on the bridge. The system was operating well with the exception of SST.

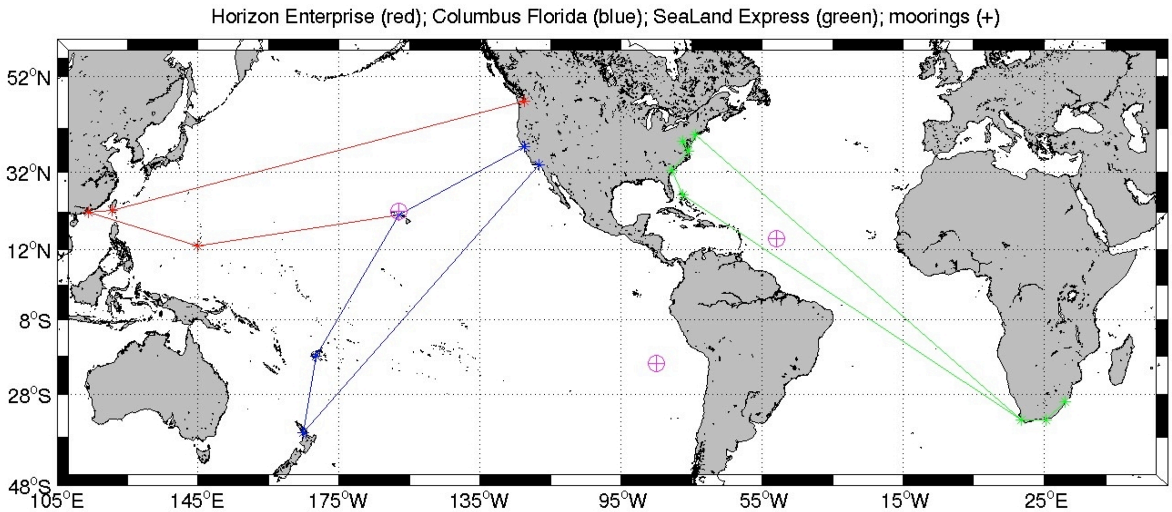
- May 2004. Frank Bahr visited the ship in Elizabeth, NJ to trouble shoot the SST system. The SST sensor (SeaBird 48) self records one-minute data but was not being transmitted via the HullCom (acoustic modem) to the logger on the bow mast. The “Local” and “Remote” HullCom units were re-located to try to get a better acoustic path. The system was still not working properly. The SST and HullCom units were removed from the ship and returned to WHOI. The units were tested and WHOI and found to be operating properly, pointing to the acoustic path as the problem. It is possible to re-locate the “Remote” HullCom so that the acoustic path is very short by using a 100-foot long cable between the “Remote” HullCom and the SBE48. This will be installed in June.

- June 2004. Frank Bahr and Laura Hutto reinstalled the SST and HullCom units on the SeaLand Express in Elizabeth NJ. There are reports of high wind “spikes” in the data, therefore a new WND module will be taken to the ship as well as a new IMET GPS to monitor “real wind” in post processing. The “real wind” currently is calculated in the NOAA SEAS 2000 system using the SEAS GPS data.

- August 2004. The wind sensor encoder failed and was replaced when the ship was in Baltimore, MD. Encoder failures seem to be due to overvoltage from the power supply coupled with ship power surges.

- October 2004. The system was turned around in Baltimore, MD. The data will be processed and be available on the web. The in port time was very short and the SST could not be serviced since there was welding in the hold that the SST is located in. A SST replacement is planned when the ship returns to Baltimore. The existing batteries should maintain SEAS data from the SST through December 2004 and the SST logger will continue until May 2005 even without battery changes.

<u>ROUTE MAP</u>



Note the Ocean Monitoring Stations (circle with cross) being operated by WHOI.

FY 2005 Plans

Office of Climate Observation, Climate Observation Program
by Mike Johnson

FY 2005 PLANS

The third Annual System Review will be held in Silver Spring, April 25-27. In addition the Office of Climate Observation (OCO) will host a meeting of the JCOMM Observations Coordination Group in conjunction with the System Review, April 28-29.

Advancements across all networks are planned in FY 2005 and are outlined in the individual reports that follow. The global ocean climate observing system will surpass the 50% completion milestone. Some significant highlights include:

- *Documenting long-term trends in sea level change*: Tide gauge stations, particularly in the Indian Ocean, will be upgraded for real-time reporting to contribute to the international tsunami warning system as well as to climate change monitoring. Transition from NASA to NOAA responsibility for the long-term support of the Harvest Platform altimeter calibration station will be completed.
- *Documenting the ocean's heat exchange with the atmosphere*: A significant observing system milestone will be achieved in September 2005. The Global Drifting Buoy array will reach its design capacity of 1250 drifters, thus becoming the first component of the Global Ocean Observing System to be completed. It has taken 10 years since the international community set out on the GOOS quest with the publication of the *Scientific Design for the Common Module of the Global Ocean Observing System and the Global Climate Observing System* by the Ocean Observing System Development Panel in 1995. A special celebration will be held during the second JCOMM Assembly in Halifax in September 2005 to commemorate this achievement and ceremonially deploy Global Drifter #1250. Expansion of the Tropical Moored Buoy network into the Indian Ocean will continue. Three sites were established in November 2004 by NOAA/PMEL in cooperation with Indian partners and two additional deployments are planned in 2005. In the Atlantic Ocean, PIRATA will be extended in cooperation with Brazil and France with two new moored buoy sites being established in the South West Expansion off the coast of North East Brazil.
- *Documenting the ocean’s storage and global transport of heat*: The transition of the Indo-Pacific high-resolution XBT lines from NSF to NOAA long-term support will be completed. NOAA will thus become the sole agency of the United States supporting this sustained component of the international system. NSF will shift their funding to new CLIVAR research. In cooperation with the Brazilian navy, a new high resolution XBT line will be established to monitor meridional ocean transport across the western Atlantic.
- *Documenting carbon sources and sinks*: The global inventory of ocean carbon is needed at least once every 10 years. Systematic surveying of the ocean was initiated in partnership with NSF but the level of funding was only adequate for NOAA to complete its contribution to the global effort in at best 14 years. In FY 2005 NOAA will augment the project to bring the rate of survey up to the required 10-year cycle. Two new moored buoy sites will be established for long term ocean carbon monitoring, one in the Pacific and one in the Atlantic.
- *Data management*: A new tariff rate for data processing within the international Joint Tariff Agreement, which supports the Argos satellite data transmission/distribution system, will establish OCO as a preferential bulk user. OCO is the largest single government user of the Argos system in the world. The new agreement will transfer all primary and supplement costs to central management at OCO and will save an estimated 45% in data processing costs system wide. Global data base operations at the ocean data assembly center at NDBC will become

operational, thus combining Global Telecommunications System (GTS) and web based data sources into a single data base for near real time observing system monitoring.

- *Product delivery and observing system evaluation*: In 2005 OCO will begin a partnership with NCEP for routine delivery of ocean analysis products based on NCEP's operational Global Ocean Data Assimilation System (GODAS) output. A team of experts sponsored by OCO will begin routine evaluation of the model output products against observations with the goal of improving both the model outputs and observing system sampling strategies. The performance measure for reducing the error in global measurement of sea surface temperature that was developed in FY 2003 will serve as an example for developing three additional quantitative performance measures in FY 2005. Metrics will be developed for the Government Performance Review Assessment (GPRA) to quantitatively measure system progress in reducing errors in global measurement of sea level change, ocean carbon sources and sinks, and ocean heat storage and global transport.

Climate Observation Program
Budget ($K)
FY 04 Actual; FY 05 Planned

Network	**System Total**			Budget Line Accounts											
				C&GC		CCRI		COSP		CCRI CO2		ENSO/PACS		Other	
	FY 04	**FY 05**	**Change**	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05	FY 04	FY 05
Tide Gauges	**970**	**1345**	**375**	0	275	320	921					650	0	0	149
Surface Drifting Buoys	**2769**	**3406**	**637**	627	386	1382	2324					760	696		
Ships of Opportunity	**2487**	**2990**	**503**	306	788	1184	885					530	1317	467	0
Tropical Moored Buoys	**3625**	**4135**	**510**	600	0	0	510	450	450			2575	3175		
Argo Floats	**273**	**275**	**2**	273	275										
Ocean Reference Stations	**2819**	**3319**	**500**	0	425	2282	2445					190	377	347	72
Arctic Ice Buoys	**0**	**60**	**60**											0	60
Ocean Carbon Networks	**2875**	**3525**	**650**	0	77	0	154	1616	1873	1259	1244	0	135	0	42
SURFRAD	**210**	**0**	**-210**	105	0									105	0
Rain Gauges	**179**	**184**	**5**	149	184									30	0
Dedicated Ships	**523**	**80**	**-443**	523	80										
Service Argos Data Processing	**1525**	**1075**	**-450**	235	125	626	825					664	0	0	125
Data & Assimilation	**369**	**443**	**74**	369	343	0	100								
Analysis & System Evaluation	**658**	**1629**	**971**	358	815	0	514	0	300			300	0		
Program Management	**684**	**960**	**276**	629	960	30	0					25	0		
Overhead	**826**	**152**	**-674**	826	152										
Total	**20792**	**23578**	**2786**	5000	4885	5824	8678	2066	2623	1259	1244	5694	5700	949	448

Table 1

3.1b. Atlantic High Density XBT Lines

by Molly Baringer, Gustavo Goni and Silvia Garzoli

FY 2005 PLANS

We plan to carry out four transects along AX07, AX10, AX08 and AX18, and a minimum of two transects along AX25.

Anticipated requirements to maintain the network at status quo

Augmented funding to cover increased costs of XBTs, now $32 per probe.

Logistics requirements:

Current levels of ship availability are needed.

New data collection methods:

We are currently testing a new 8-probe autolauncher and utilizing the new SEAS 2000 software for data collection.

Expected scientific results

We intend to identify the surface signal of each zonal current identified in the AX08 transects in the upper 750m by combining the XBT-derived temperature sections and the sea height anomaly fields from altimetry. We plan to continue the estimates of the meridional heat fluxes across 30ºS (AX18) and 30ºN (AX07) and combine these results with satellite observations to produce estimates when XBT observations are not available.

3.2b. Western Boundary Time Series in the Atlantic Ocean

Project Managers: Molly Baringer and Silvia Garzoli

Scientists Involved: Molly Baringer, Christopher Meinen, Silvia Garzoli, and Elizabeth Johns

FY 2005 PLANS

Task 1, Continuous transport of the Florida Current

- Continuous cable data recording will continue.
- 4 RV Walton Smith calibration cruises are planned. Tentative dates: Dec 04; Mar, Jun, Sep 05.
- Construction of 2 new dropsondes will be completed: 1 new one with self-recording CTD sensor for temp, salinity and pressure measurements; dropsonde with faulty antenna will be repaired.
- Approximately eight dropsonde cruises will be conducted: the cruises will be closely timed near the Walton Smith cruises and the AX7 high density XBT line.
- Web site will be enhanced once data quality stabilizes.
- Test/improve cable and section processing software.
- Study the disparity between LADCP and dropsonde transport estimates.

Task 2: Deep Western Boundary Current Time Series

- The NOAA Ship Ronald H. Brown will be used for the next Deep Western Boundary Current cruise, currently scheduled for summer/fall of 2005. Station locations close to those shown in Figure 2 will be sampled (including more complete sections at 26ºN and an Abaco section out to at least 70ºW). Should weather again become an issue, the first priority will be to the stations east of the Bahamas, second priority to the stations at 27ºN in the Florida Straits.
- The inverted echo sounders already deployed will be interrogated to telemeter their data to the ship. Through cooperation with the NSF funded MOCHA program, an additional hydrographic section will be occupied in April 2005. Additional data will be downloaded at that time, thus allowing us to process DWBC data in 6-month delayed intervals.
- Continue time series of water mass changes within the Deep Western Boundary Current.
- Compare section data across the Deep Western Boundary Current to the data from the moorings and begin construction of a transport time series.

Logistics requirements (e.g., shiptime)

Current levels of clearance and ship time are needed. The number of Sea Days requested should be maintained in spite of mechanical or logistical considerations that may affect the Ronald H. Brown schedule. Adequate resources must be made available to the Ronald H. Brown in order to assure that all scientific equipment is in proper working order to meet the science objectives.

New data collection methods

Add Task proposed to purchase backup recording equipment; instrument a second cable.

Expected scientific results

This proposal is funded to conduct fieldwork and data collection. Nevertheless, continued measurements of the western boundary currents will help scientists to:

- Monitor for abrupt climate change
- Understand natural climate variability
- Determine heat, fresh water and volume transports of two major components of the thermohaline circulation

3.3b. The Tropical Atmosphere Ocean (TAO) Array

by Landry J. Bernard, III and Daniel J. Laurent

FY 2005 PLANS

TAO/TRITON Array

Plans in FY 2005 call for maintaining 55 ATLAS mooring sites and 4 ADCP mooring sites between 95°W and 165°E. We anticipate that NOAA ship time requirements to maintain the TAO portion of the TAO/TRITON array in FY 2004 to be 278 days. Most of this ship time will be on the Ka'imimoana (236 days), with additional time provided by the Ron Brown (42 days).

We expect to get TAO salinity data on the GTS in early FY 2005. Service Argos has developed necessary algorithms, and the system is being tested. TRITON salinity data are already on the GTS.

We will continue to pursue engineering improvements to the array, specifically those that relate to improved compass accuracy, wind sensor reliability, and improved velocity measurements.

TAO Project staff will participate in the drafting of technical reports regarding measurement accuracy and sensor performance. The Project Director continues his analysis of TAO and related data sets, and his public service. Paul Freitag will continue his service as TAO representative to the DBCP and has already represented the Project at the October 2004 meeting of the DBCP in Chennai, India.

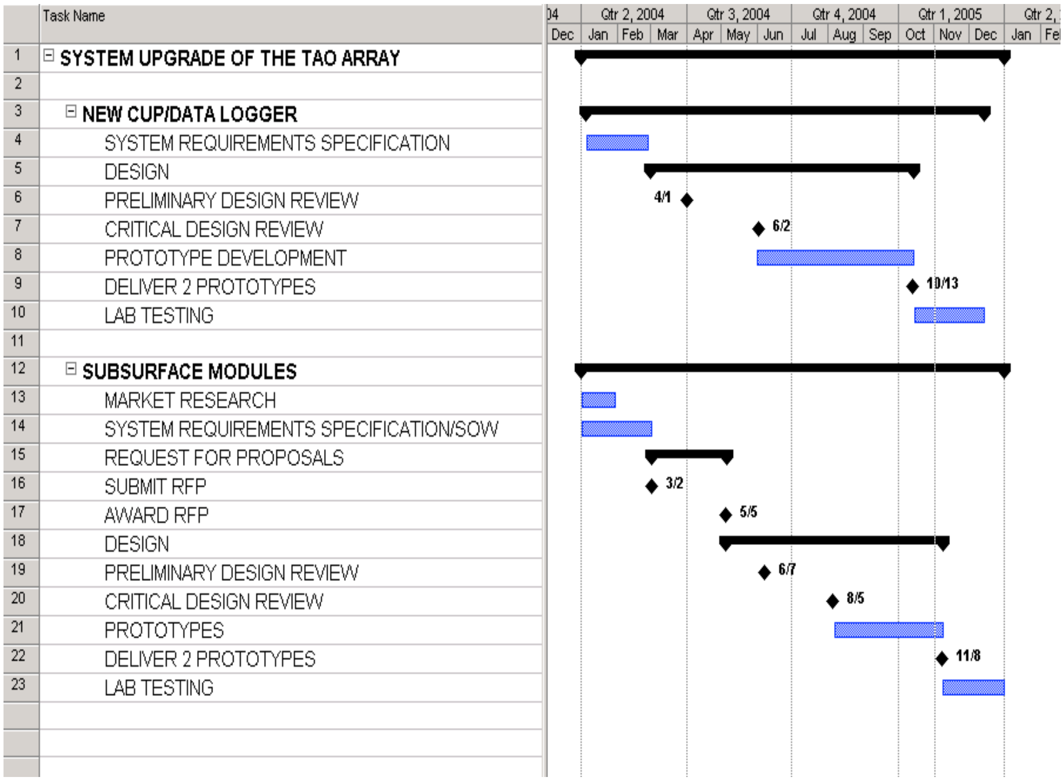
We will provide assistance to Oregon State University in their development of a new instrument to measure temperature gradient microstructure from a deep-water mooring. An initial test deployment from an ATLAS mooring is scheduled for the 4th quarter of FY 2005.

FY 05 TAO Transition Plans

a. Maintain the existing TAO array at current availability.
b. Establish the NDBC tropical mooring data assembly center (DAC) using NDBC's Technical Services Contract and operate in parallel with current TAO Data Center at PMEL. DAC will provide Quality Assurance (QA/Quality Control (QC) of all data for both research and operational users, maintain TAO data base, maintain TAO data on web site, and distribute data via the NDBC web site, an IOOS DMAC standard distribution mechanism (i.e. OPeNDAP and GTS).
c. Prepare DAC Statement of Work (SOW) to design, integrate, test, and operate the NDBC DAC.
d. Establish liaison with JAMSTEC to document JAMSTEC requirements and integrate JAMSTEC's data into NDBC DAC.
e. Establish NDBC/PMEL TAO Transition Team in Seattle.
f. Provide a Technology Refreshment Plan to the Climate Program for approval and replace any obsolete array components as available funding allows.
g. Ensure TAO array assets (i.e., buoys and ship resources) are available for research activities.
h. Provide next generation mooring proposal to Climate Program for approval.
i. Inventory TAO array and place under NDBC's management.

Schedule

The following schedule starts when the proposal is awarded and the funds are available.


Task Name
Qtr 2, 2004
Qtr 3, 2004
Qtr 4, 2004
Qtr 1, 2005
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
1 SYSTEM UPGRADE OF THE TAO ARRAY
2
3 NEW CUP/DATA LOGGER
4 SYSTEM REQUIREMENTS SPECIFICATION
5 DESIGN
6 PRELIMINARY DESIGN REVIEW
7 CRITICAL DESIGN REVIEW
8 PROTOTYPE DEVELOPMENT
9 DELIVER 2 PROTOTYPES
10 LAB TESTING
11
12 SUBSURFACE MODULES
13 MARKET RESEARCH
14 SYSTEM REQUIREMENTS SPECIFICATION/SOW
15 REQUEST FOR PROPOSALS
16 SUBMIT RFP
17 AWARD RFP
18 DESIGN
19 PRELIMINARY DESIGN REVIEW
20 CRITICAL DESIGN REVIEW
21 PROTOTYPES
22 DELIVER 2 PROTOTYPES
23 LAB TESTING
4/1
6/2
10/13
3/2
5/5
6/7
8/5
11/8

3.4b. ENSO Observing System, XBT component, Task 1-Operations

by Steven K. Cook and Robert L. Molinari

FY 2005 PLANS

Anticipated requirements to maintain the network at status quo
The $32 cost per probe will continue through this fiscal year.

Expected scientific results
Further definition of the spatial patterns of important decadal signals in upper ocean thermal structure in all three-ocean basins, characterization of the decadal signals of these signals and nowcasts of the phase of these signals.

3.5b. CORC: Surface Fluxes and Analysis
by Dan Cayan

FY 2005 PLANS

1. Update estimates of heat flux (short wave, long wave, latent and sensible), moisture flux (evaporation), and momentum flux from COADS data through summer 2004 for individual observations and for monthly aggregates of daytime and nighttime periods.

2. Evaluate daytime vs nighttime differences of fluxes and key variables. Examine diurnal variability of fluxes and key variables to understand the daytime vs. nighttime differences. Focus on eastern North Pacific, but include whole Pacific and Atlantic as a basis for comparison.

3. Evaluate variability of the daytime and nighttime heat fluxes in connection with the changes in sea surface temperature and with available observational estimates of heat storage changes. Focus on eastern North Pacific, but include whole Pacific and Atlantic as a basis for comparison.

4. Distribute monthly flux data via FTP server with web site interface to describe dataset and bulk formuale employed. Requests for individual weather observations and associated flux estimates will be handled on an individual basis.

3.6b. CORC: Four-Dimensional Variational (4DVAR) Data Assimilation in the Tropical Pacific
by Bruce Cornuelle, Detlef Stammer and Art Miller

FY 2005 PLANS

After a detailed analysis of the different assimilation runs, we will examine the forecast skill of our assimilation system. The length of the assimilation period will be extended to several years and most of the CORC data will be also used in our assimilation system. The assimilation of profiles data is expected to reveal a crucial need of using smoothed error covariance matrices in the 4DVAR cost function. This last point will be carefully examined in our future work. We also aim at adjusting the mixing parameters by including them in the control vector in order to improve the quality of our analysis, particularly in the deep ocean. This work will produce a time-evolving ocean state estimate and an improved set of forcing and boundary conditions. These products will be analyzed to quantify forcing errors and to examine the detailed ocean structure and dynamical evolution through several ENSO cycles. The complete set of products (ocean state, forcings and boundary conditions) will be made available to the community for general scientific studies in tropical Pacific.

Figures

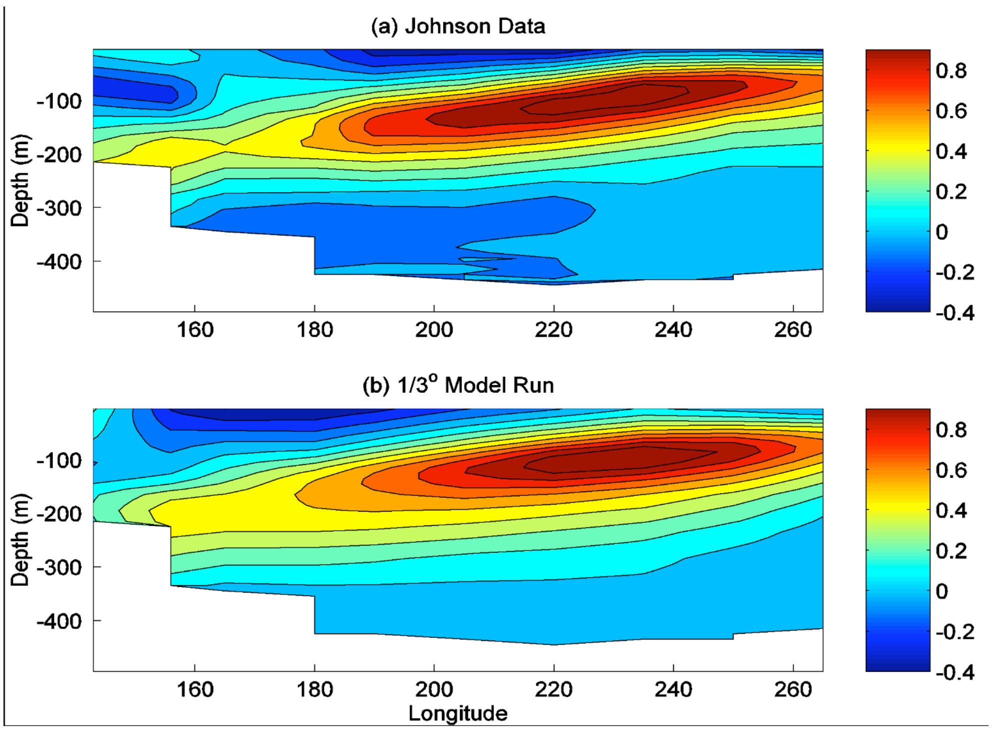


Figure 1. Mean Zonal Velocity on the equator from (a) Johnson data, and (b) 1/3° MITgcm free-run without assimilation.

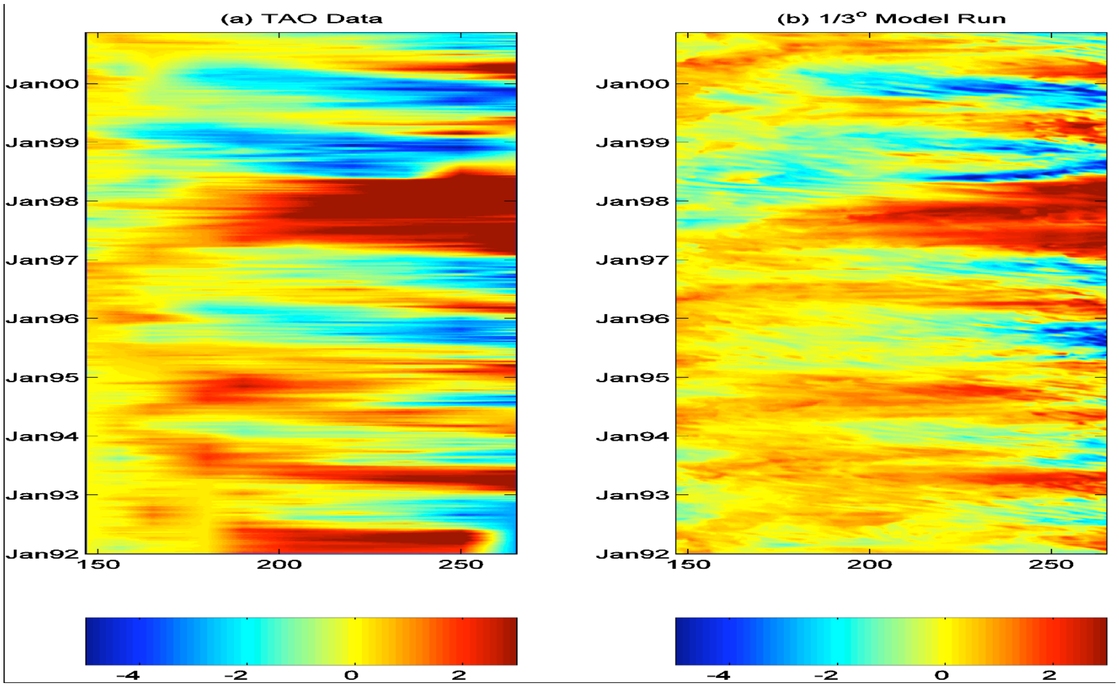


Figure 2. Sea surface temperature anomalies on the equator from (a) TAO data, and (b) 1/3° MITgcm free-run without assimilation.

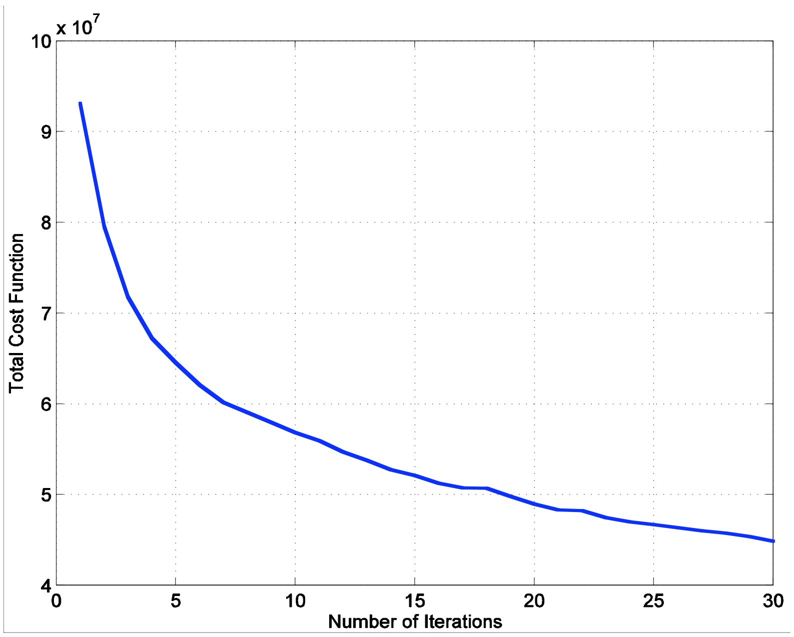


Figure 3. Evolution of the total cost function (over 1 year assimilation period) as function of the number of iterations.

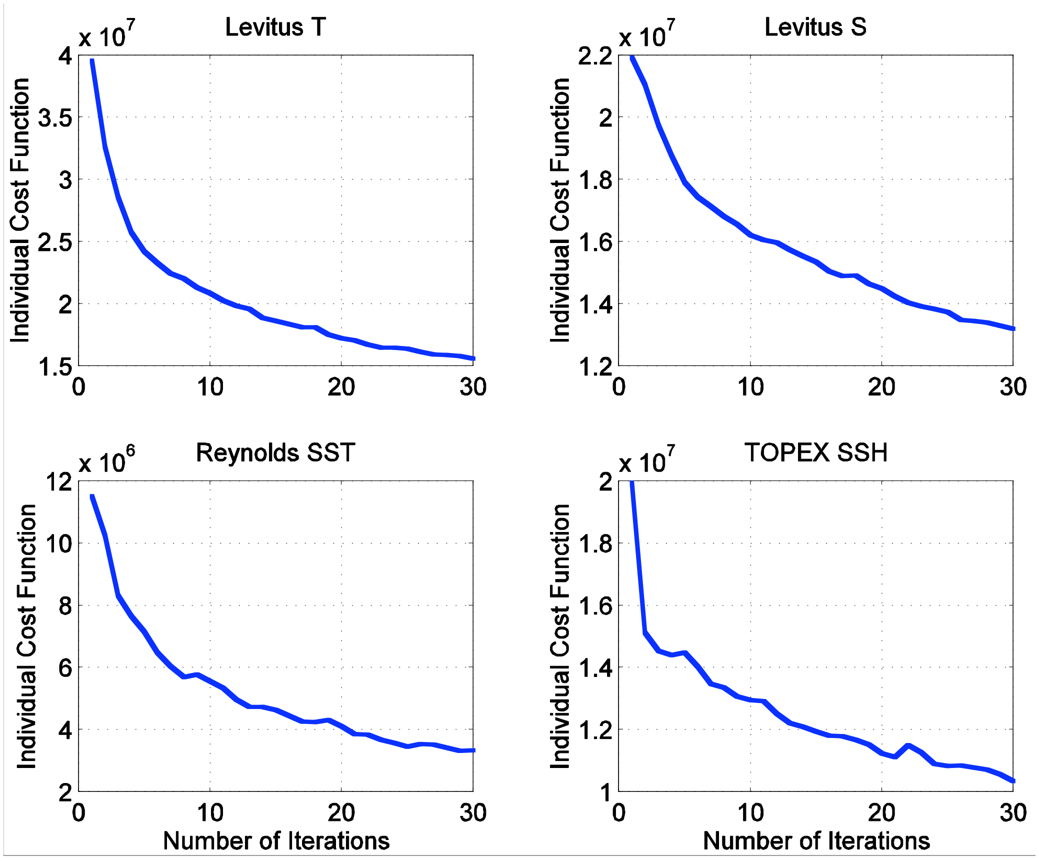


Figure 4. Evolution of the individual cost function observation terms (over 1 year assimilation period) as function of the number of iterations.

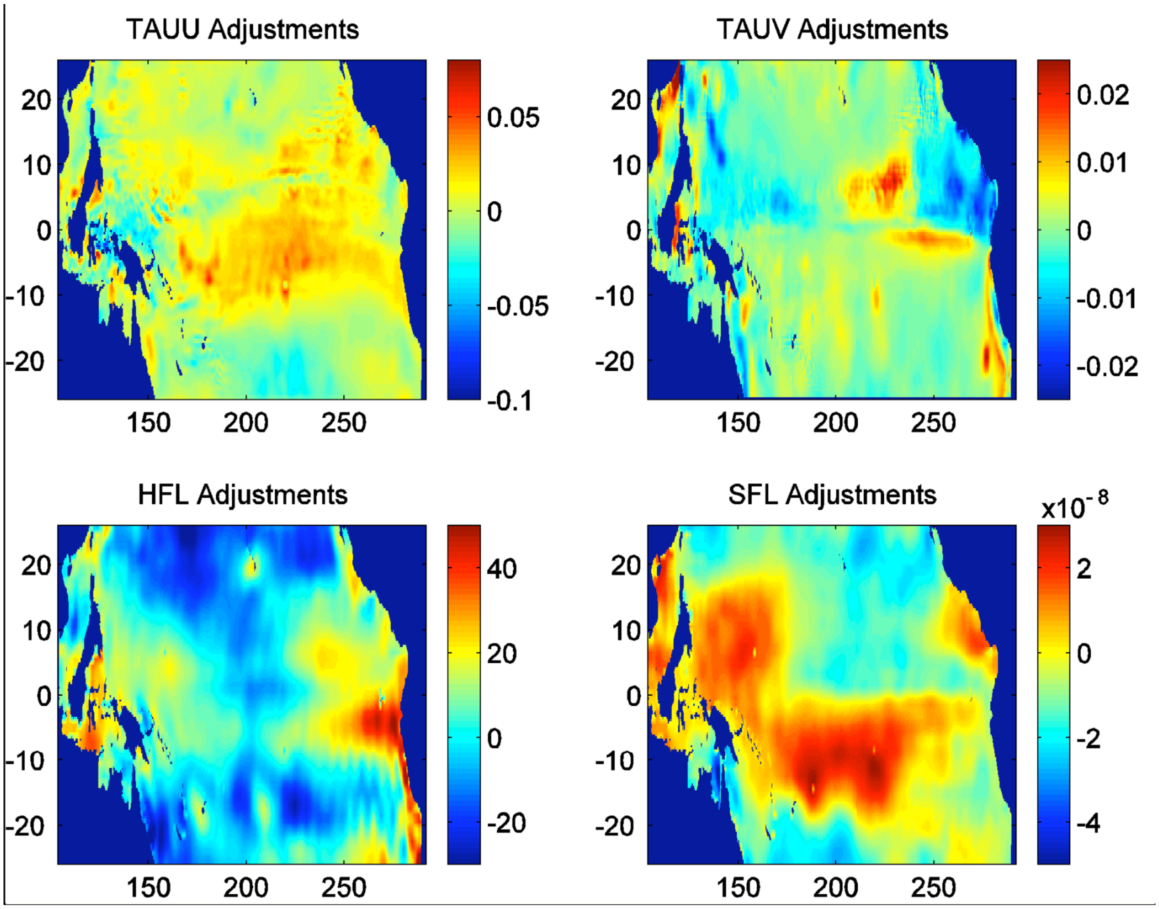


Figure 5. Mean adjustments to the NCEP forcing fields as estimated by the 4DVAR assimilation.

3.7b. CORC: Underwater Gliders for Monitoring Ocean Climate

by Russ E. Davis

FY2005 PLANS

Equipment Acquisition. To date we have completed 3 Spray gliders for this program and lost one through collision with a surface vessel. One remaining glider has been upgraded with an ADP and the other with a Sea Bird CTD. During FY05 we will complete 3 new Spray gliders now under construction and fit all with SBE CTDs and Sontek ADPs. We will also begin construction of the final 3 gliders to be built under this program.

Technical Development. The technical improvements introduced in FY04 need long-term testing for reliability and effectiveness. We will complete the final development on our list by installing optical sensors (chlorophyll-a florescence and optical backscatter) inside the pumped system where they can be protected from bio-fouling. This will require field testing for effectiveness and to verify accurate readings in the new circumstances.

Pilot Repeat Section in the California Current. The technical developments all require long-term field tests and we will use this as an opportunity to add to the climate record. One of the longest extant ocean climate time series is the CalCOFI program's 54 year sampling of the California Current System (CCS). This record clearly shows how climate variability, most notably connected to the ENSO and PDO cycles, influences the physical structure of the CCS and the structure and abundance of biological communities that live in it. NOAA Fisheries is in the process of proposing for FY 2007 a Pacific Coastal Ocean Observing System (PaCOOS) that will combine and coordinate stock assessment surveys, extended climate/ecological sampling of the CalCOFI type, and more modern methods to monitor the CCS along the entire west coast of the U.S.

Today's CalCOFI surveys are low resolution in time (quarterly) and space (71 km), better suited for providing many independent samples of biology than for characterizing the important mass, heat, nutrient and freshwater transports of the upwelling cell, the poleward California Undercurrent and the equatorward California Current. In the spirit of an Integrated Ocean Observing System (IOOS), we propose to begin higher density sampling roughly along CalCOFI Line 93 that tends 700 km southwestward from San Diego. Our hope is that the NOAA Fisheries PaCOOS effort and the new California Current LTER program, both aimed at characterizing the ecological response to climate variations, and the Climate Observing Program will find the resultant data valuable enough to continue. Indeed, it is our frustration that at this time the planning for ocean observations of climate variability and of ecological response to climate variability are proceeding without adequate coordination or an eye to the things that will impact most on both these programs.

3.8b. CORC: High Resolution XBT/XCTD (HRX) Transects

by Dean Roemmich, Bruce Cornuelle, and J. Sprintall

FY2005 PLANS

During FY2005 it is planned to collect 4 transects along each of the routes listed in Table 1: PX37/10/44 (San Francisco-Honolulu-Guam-Taiwan), PX38 (Honolulu-Alaska), PX81 (Honolulu-Chile), PX08 (New Zealand-Panama), PX06/30 (New Zealand-Fiji-Los Angeles), IX15/21 (Fremantle-Mauritius-Durban), PX30 (Fiji-Brisbane, collaborative with CSIRO) and PX34 (Wellington-Sydney, collaborative with CSIRO). Travel by ship riders to and from ports at end points of XBT transects is included in the budget, along with estimated cost of ship passage based on previous experience. On some transects under our management it is cost effective to hire ship riders from CSIRO, and the budget entry for CSIRO vessel services is for that purpose.

The lines will be sampled at the usual HRX resolution of 30 – 50 km in ocean interiors and 10 – 20 km in boundary and equatorial regions. This will require approximately 6,245 Sippican Deep Blue XBT probes. XCTD sampling will continue in areas that are inadequately sampled for T/S variability by Argo floats and experimental T-12 XBT probes will be deployed when they become available. We will continue to provide ancillary logistical assistance for the VOS IMET program and for Argo float deployments.

Overall management of the program is the responsibility of D. Roemmich, in consultation with Co-PIs B. Cornuelle and J. Sprintall. The PIs will set priorities for the program consistent with the recommendations of the 1999 Upper Ocean Thermal Review as well as other relevant international bodies (Ocean Observing Panel for Climate, CLIVAR Global Synthesis and Observations Panel) and the Ten Climate Monitoring Principles. Participation by D. Roemmich is at no cost.

The Operations Manager of the HRX Program is G. Pezzoli. He is responsible for scheduling of transects, for liaison with ships, ship owners and ship management, for training and scheduling of ship riders, and for logistical support of cruises including equipment and probes. He is occasionally a ship rider. The other full-time technical staff person is V. Cannon. She is responsible for frequent ship riding, for laboratory fabrication, preparation and testing of equipment, and to assist with ship rider training and with shipping. Other technical staff (D. Cutchin, B. Stanton, J. Afghan, and unnamed) are part-time ship riders. They are responsible for data collection activities not carried out by the full-time staff. Their time is budgeted in proportion to the number and length of cruises presently anticipated for FY2005. Pezzoli and Cannon will be responsible for conversion of the present autolauncher systems to the new Windows/MK21 hardware and software.

The Data Manager is L. Lehmann. She is responsible for data storage and access, for web site maintenance, and is the principle programmer for the SIO XBT Autolauncher System. She will complete the software development for Windows/MK21 operations. Along with J. Gilson, she provides scientific programming support. Data quality control is the responsibility of G. Pezzoli and ship riders, with final review by D. Roemmich.

3.9b. CORC: Development of an Underway CTD

by Daniel L. Rudnick

FY 2005 PLANS

The most important technical challenge for the coming year is to establish confidence in the UCTD conductivity sensor. To this end we plan a complete reevaluation of the sensor and associated electronics. Necessary changes to the system will be a priority of the coming year.

Expanding the user base of UCTD is a key goal. A cruise aboard the NOAA R/V Jordan is planned in collaboration with NOAA Fisheries scientist Valerie Andreassi. We plan to train NOAA personnel in UCTD operation so that they may assess whether the system meets their requirements.

Continued expansion of UCTD stocks is planned so that we may support additional cruises during the coming year. Several scientists and institutions have contacted us with interest in UCTD. Determining how best to address their needs is a considerable task for 2005.

3.10b. CORC: Lagrangian Salinity Profiling: Evaluation of Sensor Performance
by Raymond W. Schmitt

FY 2005 PLANS
We will continue to help improve salinity performance of profiling floats through laboratory testing and development of data processing algorithms.

3.11b. CORC: Observations of Air-Sea Fluxes and the Surface of the Ocean

by Robert A. Weller, Frank Bahr, and David S. Hosom

FY 2005 PLANS

Turnaround of the AutoIMET systems on all ships will be carried out every six months.

The original stand-alone ASIMET modules will all have been converted to the new Auto-IMET systems and these will have been installed on the three active ships, Horizon Enterprise, Columbus Florida, and Sealand Express. A fourth ship is scheduled to have a system installed in 2005 making a total of four VOS with Auto-IMET / NOAA SEAS systems that report via Inmarsat C in real time and store one minute data for retrieval every six months. This program is in an operational support mode for the current ships.

3.12b. Flux Mooring for the North Pacific's Western Boundary Current: Kuroshio Extension Observatory (KEO)

by Meghan F. Cronin, Christian Meinig, and Christopher L. Sabine

FY 2005 PLANS

KEO-1 operations

The KEO buoy was deployed in June 2004. Therefore in FY05, we will be carefully monitoring the buoy data. Having near-realtime data allows for accelerated scientific analyses of the data. During FY05 there is likely to be a science meeting on the Kuroshio Extension System Study. There has already been lively internet discussion about the role of the recirculation gyre in stabilizing the path of the Kuroshio Extension. In June 2005 on the KESS leg-1 cruise aboard the R/V Revelle, all sensors will be swapped with new sensors, and the buoy platform will be replaced with one containing the pCO_2 flux sensor. Cronin and one PMEL mooring technician will participate in this cruise. Cronin will be responsible for the carbon measurements.

3.13b. High Resolution Climate Data From Research and Volunteer Observing Ships

by C. W. Fairall

FY 2005 PLANS

The major effort in FY05 will be execution of the TAO and WHOI climate buoy cruises plus continued work on the *Ronald Brown* C-band radar. Approximately 40 days of air-sea flux data will be obtained on the TAO cruise and about 20 days of data on the WHOI cruise (Stratus04). A second component will be construction of the roving flux standard. Ship time for the flux standard development will be used in 'piggyback' mode for the existing projects. The new laser wave gauge was tested on NEAQS and will be deployed for the first time on TAO and Stratus04. Besides collecting the high-resolution flux data, we will be doing pilot study evaluation of a UNOLS ship (R/V *Revelle*) IMET system as part of our plans to upgrade the research vessel climate data. The ETL seagoing flux system will provide the roving standard. Construction will begin on the High Resolution Climate Observations website. The first task will be compiling material for the online handbook for flux observations. We also plan to update our ship database so that all cruises through 2003 are publicly available. Joint analysis projects with WHOI and PMEL will continue. We are also proposing to add a second task to connect this project to the Carbon Cycle program. This new task is to build a fast CO_2 system so we can set up a CO_2 flux reference site. This work would be done with the group from Southampton, UK. The site will be OWS "*Mike*" (66°N, 2°E), which is situated in a regime with some of the Earth's largest annually-averaged CO_2 fluxes (5 to 9 Tg C yr^{-1} per 4 ° x 5° area; Takahashi *et al*. 1997).

For the Ronald Brown radar systems project, the recent installation of the two new computers and software upgrades puts us in an excellent position for ongoing radar observations. Laser leveling of the antenna motion stabilization (INU) should be performed in port every few years; and will be scheduled. The Sigmet software licenses and maintenance will also need to be continued (this is k$9 per year). In the next year or so, we may need to install a completely new version of the software at significant expense.

Outreach efforts during the reporting period center on educational contacts through the University of Colorado CIRES Outreach program and the NOAA Teacher at Sea program. For the TAO cruise a link has been set up for twice-weekly exchanges with 10 middle school classes around the US. This project has been dubbed 'Ocean Interactions' and can be found at: http://cires.colorado.edu/~k12/interactions/. The WHOI climate buoy cruise will have two NOAA Teachers at Sea on board.

3.14b. Global Repeat Hydrographic/Co_2/Tracer Surveys In Support Of CLIVAR And Global Carbon Cycle Objectives: Carbon Inventories And Fluxes

by Project Managers: Richard A. Feely and Rik Wanninkhof
Co-Principal Investigators: Christopher Sabine, Gregory Johnson, Molly Baringer, John Bullister, Calvin W. Mordy, Jia-Zhong Zhang

FY 2005 PLANS

Anticipated Requirements to Maintain the Network at Status Quo:
The A16S and P16S cruises will be completed in January-March 2005 timeframe. The NOAA budget for FY05 covers costs required to finalize the data from the 2004 reoccupation of WOCE Section A20/22 and P2 cruises and to pay for outstanding costs for that section that were incurred in FY04.

Logistics Requirements (e.g., ship time):
We have been given 45 days of NOAA ship *Ronald H. Brown* ship time for the A16S cruise in the South Atlantic in 2005. We need to obtain new support for the FY 2006 cruise in the Pacific (P16N) as well as support for the underway pCO_2 measurements on the Repeat Hydrography cruises in the Pacific.

New Data Collection Methods:
New CTD oxygen sensors (SeaBird Electronics model 43) will be used on this cruise. With these two sensors, preliminary calibrations had typical standard deviations between sensors and water samples of 1 μmol kg^{-1} (0.5%). Also new (refined design) water sample bottles fabricated at PMEL for the 2003 A16N reoccupation worked very well, with effectively no evidence of leaking bottles.

Expected Scientific Results:
In FY05, NOAA will take the lead for core hydrographic measurements on the Repeat Hydrography Program reoccupation of A16S on the NOAA Ship *Ronald H. Brown*. The science leg for that cruise is presently scheduled for 45 days of ship time, departing from Punta Arenas, Chile, and arriving in Fortaleza, Brazil, with additional ship time for transit to and from these remote locations. NOAA will be in charge of CTD/O_2 data collection, calibration and processing, bottle salinity measurement, bottle oxygen and nutrient measurements, and underway pCO_2 and bottle carbon measurements. We anticipate occupying roughly 117 CTD stations along the line, with almost 4,000 water samples collected for analysis. The A16S section was last occupied in 1989. It is difficult to predict what differences in heat, freshwater, and biogeochemical parameters will be observed in the 16-year interval. Of course significant increases in carbon storage are expected, and heat storage seems likely to have increased in the interval as well. In many of the other ocean gyres reduction in oxygen within the subpolar thermocline has been observed, along with subpolar freshening and increases in subtropical saltiness. If these changes are also seen in the western Basin of the South Atlantic, it will suggest that the changes are of global extent, providing a modeling challenge.

The A16N, A20/22, A16S, P2 and P16S cruises will provide the necessary data required to assess changes in the Atlantic and Pacific Oceans of anthropogenic carbon and biogeochemical cycles in response to natural and/or man-induced activity. Global warming-induced changes in the ocean's transport of heat and freshwater, which could affect the circulation by decreasing or shutting down the thermohaline overturning, can be determined from the long-term observations derived from these cruises when combine with other results from the international community.

Travel is to embark on the cruise in Papeete, Tahiti and disembarking in Wellington, New Zealand. Shipping is for transport of equipment and PMEL CO_2 van to Papeete and return from Wellington. This budget covers the shipping of the PMEL CO_2 van and equipment. Three and a half months each of personnel time is allotted to complete the carbon data for A20/22 and P2. A key goal of the Repeat Hydrographic CO_2/tracers Program is the detection of changes in the global ocean and the investigation of their causes. In order maximize the utility of these data sets, careful data quality evaluation is required. This includes examination of the internal consistency of the data sets, comparison with complementary parameters collected on the expedition and comparison with existing and historical data using statistical methods. Drs Richard Feely and Chris Sabine are experienced in these techniques and will apply these methods to improve data quality evaluation for the repeat hydrography program. The methods developed should be of great value for the community in the future. Marilyn Roberts and Dave Wisegarver will process the data sets from the A20/A22 and P2 cruises and P16S data sets. Chris Sabine and Marilyn Roberts, or an alternate to be determined, will participate on the P16S cruise.

The AOML CO_2 Group will lead the A16S cruise in the South Atlantic scheduled for January/February 2005 as well as perform DIC and pCO_2 measurements. This includes planning and coordination efforts, with respect to shipping, personnel, and ship-science interaction. A web site to disseminate cruise information has been set up: www.aoml.noaa.gov/ocd/gcc/a16s. In accordance with our UNOLS repeat hydro counterparts we allocate funds for these efforts that includes 6-months of personnel time for organizational purposes, a CTD watch stander and travel for chief scientist's party.

AOML will perform the DIC and pCO_2 discrete measurements. The underway pCO_2 measurements will be done by AOML as well but this is covered under a different contract. Two qualified analysts will be sent to sea for DIC analysis and one for pCO_2 discrete analysis. To account for effort preparing and post cruise data reduction and work-up we use the formula multiplying the seadays by three for the shore based salary component. The personnel works on 12-hour shifts and appropriate overtime compensation is included. Travel is to embark on the cruise in Punta Arenas, Chile and disembarking in Fortaleza, Brazil. Shipping is for transport of equipment and CO_2 van and a storage van to Punta Arenas and return from Barbados. This budget covers the shipping of the AOML nutrient, O_2, and hydrography equipment and the equipment for alkalinity and pH measurements performed by the group of Prof. Millero from RSMAS. Two months of personnel time is allotted to complete the carbon, oxygen, and nutrient data report for A16N.

The AOML Hydrography budget includes ET support at AOML; 3 months for one ET attending the cruise, plus 1 month for instrument preparation/maintenance. Also, 1 month of technician support for instrument preparation, etc. Travel for one person to sea, and one person to the OCO annual review. Permanent equipment includes additional Niskin bottles for the 24-position 10-L rosette. (AOML's supply includes only 50 bottles in stock 2-24 position frames, plus 1-12 position frame).

The NOAA hydrography budget is apportioned roughly 90% to operations, 5% to data management, and 5% to research and development. The program is primarily funded to collect, calibrate, and process hydrographic data, which is an operational function. The WOCE Hydrographic Program Office at SIO handles the bulk of data management for the hydrography program. However, interacting with them and NODC does require some part of our effort be put toward data management. In addition, we always have one eye out to upgrade our measurement techniques and improving efficiency by improving our calibration software, upgrading hardware, and the like. This means that a small portion of our effort is aimed towards research and development.

The CFC Tracer Group. The PMEL CFC group will send a CFC analyst to participate on the A16S cruise in FY 2005, sharing the analytical work with Dr. Mark Warner at the University of Washington. As outlined in the Repeat Hydro Program planning documentation, a goal of the joint CFC efforts on A16N and A16S is to ensure that analytical methods, data acquisition and processing techniques are compatible among the groups, and to enhance the development and transfer of improved methodology in the community. Dr. Warner will provide a CFC analytical system and the laboratory van to be used on

A16S. At present Dr, Warner does not have the capability for the analysis of carbon tetrachloride, so the PMEL group will provide this analytical system for the A16S cruise. Dr Warner will provide shipping costs for the analytical systems. Preliminary CFC and carbon tetrachloride concentrations will be calculated and made available during the cruise and the data set will be included in the data release at the end of the cruise. Final data processing will be done after the completion of the cruise, in accordance with the Global Repeat Hydrography/CO_2/Tracer Program data distribution policies.

J. Bullister will focus on the analysis, interpretation, and publication of results from this program. CFCs, together with other parameters collected as part of the repeat hydrography program, are key tracers for studying the rates and pathways of ocean ventilation processes. The CFC data will be of use in testing numerical models for circulation and transport. CFC data also provide information on the 'ages' of water and are essential in the calculation of anthropogenic CO_2 in the ocean based on the C* and other techniques. These data will be used in helping to estimate the vertical penetration of anthropogenic CO_2 and the flux of anthropogenic CO_2 in the ocean.

A key goal of the Repeat Hydrographic Program is the detection of changes in the global ocean and the investigation of their causes. In order to maximize the utility of these data, careful quality evaluation is required. This includes examination of the internal consistency of the data sets, comparison with complementary parameters collected on the expedition and comparison with existing and historical data using statistical methods. We have found, in comparing older data with new data, that statistical comparisons of CFCs with concurrently measured tracers (*e.g*., T, S, O_2) can be useful in evaluating possible calibration and sampling biases in the CFC data sets. Dr. Rolf Sonnerup is experienced in these techniques and will assist in the development and testing of new methods to improve CFC data quality evaluation for the repeat hydrography program.

During FY 2005 we will upgrade our data acquisition systems. We plan to focus on improved methods for the simultaneous measurement of CFC-12, CFC-11, CFC-113 and carbon tetrachloride on the same analytical system. This should eliminate the need for multiple analytical systems and streamline the analysis and data processing.

3.15b. Surface Drifter Program

by Silvia L. Garzoli and Robert L. Molinari

FY 2005 PLANS

Anticipated requirements to maintain the network at status quo:

Globally deployments: over 700 Drifters will be deployed which will increase our shipping costs by about 50% or $25K for a total of $72K.

Logistics requirements (e.g., shiptime):

None

New data collection methods:

None

Planned deployments:

For FY05, plans are to deploy the following numbers of drifters:

- Tropical Atlantic (20ºS-20ºN): 175
- Extra-tropical Atlantic (20ºS-40ºS): 45
- Operations globally (less Atlantic): 480

Expected scientific results:

This proposal is funded to conduct the fieldwork and the data collection. Nevertheless, use of the data for scientific purposes by AOML scientist is expected. Science plans are as follows:

Atlantic component: (1) Analyses to map the distribution of eddy energy, examine Lagrangian spectra at time scales of mesoscale fluctuations, map and explain the distribution of Lagrangian length and time scales which characterize oceanic dispersion, and explore the role of eddy flux terms in the time-mean momentum budgets of the tropical Atlantic Ocean. (2) Characterize the near-surface circulation of the South Atlantic Ocean. Particular focus will be on the time-mean pathways of the boundary currents (Confluence of Brazil and Malvinas; the Agulhas/Benguela system) and the variations of the upper ocean exchanges associated with the meanders in the South Equatorial Current's bifurcation at the coast of Brazil.

3.16b. National Water Level Program Support Towards Building A Sustained Ocean Observing System For Climate

by Stephen K. Gill and Chris Zervas

FY 2005 PLANS

Task One:

CO-OPS will extend the compilation of the data and the reports from the 18 NWLON stations to include all 62 global reference stations assuming routine data availability each year. Efforts will concentrate on getting the data compiled in a timely fashion and generating routine reports established in the first year effort. Success will depend upon the ability to get timely data from all stations. These efforts will be coordinated with PSMSL, GLOSS and UHSLC programs.

Task Two:

Upgrades will be completed a two critical ocean island stations at Midway and at Guam. Upgrades will include installation of redundant sensors and DCP's and connection to geodetic datum using GPS. Efforts will be made to make connection between tidal benchmarks and existing CORS systems.

Task Three:

Operation and maintenance of Platform Harvest tide station will continue as required using OGP funding. The MOA with JPL/Caltech will expire. Coordination of Platform activities will continue to be coordinated with JPL scientists.

3.17b. An End-to-end Data Management System for Ocean pCO_2 Measurements
by Steve C. Hankin, lead PI, Richard Feely, Alex Kozyr, Tsung-Hung Peng

FY 2005 PLANS
The work that was begun in year one of this effort (FY05) was deemed to be highly successful by the CO_2 Science Team. Progress along the lines initiated in year 1 will be pursued as rapidly as possible in year 2 (FY05). These particular milestones are top priorities:

PMEL milestones:

- Improved visualizations through interactions with carbon scientists develop effective visualization products for (Lagrangian) underway data. Measured values may be represented by colors (as in figure 2) or in some cases by line plots mapped to the path of the ship. The output of ODV-formatted custom subsets will be explored and implemented if it is determined to be a capability that is useful to scientists.
- Detailed selection capability outputs will be enhanced so that individual cruises may be identified by name on plots that show many cruises and may be individually selected for inspection of metadata, single cruise visualization or subsetting.
- Data-metadata integration working jointly with CDIAC the creation of bi-directional linkages will be explored to unify the management of data and metadata into a single work environment. The goal is that a scientist should be able to “click” instantly to the metadata that is relevant to data being browsed; and “click” instantly to visualizations of data relevant to metadata that is being browsed.
- Solicit community feedback the initial underway data systems will be presented to carbon scientists and other science users through presentation at the CO_2 Science Team meetings, email announcements soliciting comments and face-to-face interviews requesting detailed assessment. All aspects of the design of the system will be reviewed based upon feedback and enhancements will be made accordingly.
- Database support for hydrographic profiles - the database design will be expanded to address carbon bottle data measurements. The initial design will be employed in a demonstration LAS in preparation for further development in the following year.
- Develop data ingestion scripts working cooperatively with CDIAC develop procedures and scripts to ingest legacy underway data formats into the CDM database.
- Operationalize the underway server working with CDIAC the contents of the underway database will be expanded and the server will be “operationalized” as a stable resource for the carbon science community.

CDIAC milestones:

- Complete the public web site for the VOS project including an operationalized LAS Web server for the underway carbon data;
- Add the VOS underway data into LAS as soon as they become available in QCed and publicly releasable form;
- Work with PMEL to review and improve the presentation of underway data through LAS;
- With the assistance of PMEL and Mercury groups CDIAC will explore mechanisms to link measured data on LAS with the metadata files in Mercury;
- Attend the VOS Science Team Meeting to present and discuss data management issues.

AOML milestones:

- Reaching community consensus on improved, automated data quality checking protocols for VOS pCO_2 underway data;

- Providing protocols for data reduction and quality control from VOS pCO_2 underway systems to expedite posting of uniform high quality data.;
- Achieving community consensus on appropriate formats and metadata standards for delivery of data to the regional QC site at CDIAC;

Participation in the development of regional QC procedures to be applied at CDIAC.

3.18b. Observing System Research Studies
by D. E. Harrison

FY 2005 PLANS
It is proposed to continue to investigate the space and time scales of significant climate anomalies, via examination of the historical data sets, comparison of operational and research analyses and numerical model studies when they can sharpen knowledge of the processes that cause the phenomena of interest and affect their predictability. It is proposed also to continue to promote, and to participate where appropriate and useful, efforts by others to carry out similar activities for the suite of climate variables that are priorities for the Office of Climate Observations. Finally, it is proposed to continue the national and international technical committee activities that support the design, evaluation and strategy for evolution of the global observing system for climate.

The relevance of particular phenomena is estimated by the degree to which land weather anomalies can be associated with them or the degree to which they must be resolved by the observing system and its analyses to improve climate forecasts, to provide warning about changes in the state of the ocean, or to avoid aliasing other climate-relevant phenomena. Studies on SST, SLP, surface wind, sea level and tropical Pacific subsurface temperature and salinity will be carried out, and preparatory work to make analyses of other variables available for future study. As has been done in previous SST studies, attention will be paid to the development of performance metrics for the observing system to be able to identify and resolve the relevant variability.

The southern hemisphere subseasonal SST studies carried out with Andy Chiodi will be submitted for publication. Further work will be done on the characteristics of subtropical Indian SST anomalies and their relationships with African rainfall anomalies. We believe that there is much to be learned from case studies; in this region there is good reason to expect the EOF and CEOF analysis approach may mislead about the real fundamental characteristics of the variability and, hence, the rainfall anomalies associated with the variability. Larkin and Harrison (2003) have shown how EOF analysis distorts the actual characteristics of El Nino and La Nina events, and we expect a similar result in these Indian Ocean studies. This work will help clarify the phenomena we need the observing system to study, thereby providing justification for continued observing system expansion into the southern hemisphere oceans.

The work on subsurface temperature trends also will be completed and prepared for publication. The fundamental need for sustained global observations, if we are to have accurate trend information (much less to characterize decadal variations), will be made very clear. The importance of Argo for global coverage and repeat XBT lines and time series for better information in selected locations, will be argued.

The tropical Pacific WWE/MJO/El Nino work will be prepared for publication. Hopefully it will be possible to get the TAO/Triton website data presentation to more accurately present the energetic time scales of near equatorial winds, as one response to the paper.

It is time to extend the activities of the project beyond SST variability; even though there is more work to be done on SST for climate progress toward implementing the global SST surface drifter array is well justified by the work that has been done to date.

Preliminary studies of global mean SLP analyses have revealed non-trivial differences between operational analyses, and they are large enough to introduce a non-trivial source of uncertainty in the sea surface height variability data from altimetric satellites. These differences will be characterized more fully and a paper on them will be prepared for publication. To begin with ECMWF and NCEP analyses will be used. If comparisons with other operational SLP analyses show substantially different characteristics, these also will be summarized. Accurate knowledge of SLP changes in the mean is important for atmospheric climate change studies and climate change projection model result evaluation.

Preliminary comparison of operational surface wind analyses has also been done and has revealed continuing very significant differences in the mean wind and in the wind variability. We have been expecting the analyses to begin to compare better, but there has been no dramatic improvement; it is time to put the numbers out and see if they can motivate improvements in operational analyses. The tropical moored buoys and time series reference site moorings will provide critical in situ results for these comparisons. The surface wind vectors from QuikScat also will also be included in the comparisons.

The historical data set of tide gauge records will be made available via a Live Access Server and an OpenDap data set will be constructed. These activities will greatly facilitate access to the tide gauge records; it is hoped that the GLOSS project will accept the task of updating the data set as new data are sent to GLOSS data sites. To the extent that high time resolution records are available, a separate data set of these records will be prepared to supplement the monthly mean GLOSS records.

Efforts to create an archive of operational surface fluxes at the US GODAE server will continue, under the auspices of the new WCRP surface flux working group. DOE is not going to make resources available for this activity at LANL, which is what the SURFA project had been counting on. Because knowledge of air sea flux uncertainties is critical for GODAE operational ocean analyses, GODAE has agreed to make the server available for this purpose.

A number of sea ice products are routinely produced. Nick Rayner at the Hadley Centre has carried out some preliminary comparisons and has found substantial differences in the deduced long-term trends. It is important to foster a thorough comparison of comparable sea ice products. Efforts will be made to engage Nick Rayner and others in the community to advance sea ice comparison work.

A variety of routinely produced regional and global ocean analyses (temperature, salinity, sea surface height and currents) are now available (through GODAE projects and other projects), but their relevance for climate purposes is unclear. Preliminary comparisons of North Atlantic analyses are being carried out by GODAE participants. A strategy for comparison of tropical Pacific analyses has been prepared but no group has undertaken the comparison work to date. It is proposed to try to advance the tropical Pacific analysis comparison project, involving as many of the routinely generated analyses as possible.

At present there is no accessible summary of what fields are routinely produced by groups and how they can be accessed for comparison with each other or with observations. Such a summary will be created as a sort of ‘gap analysis’ for ocean operational and climate-relevant products. The summary will identify those regions and variables that need enhanced analysis work, and will be made available to OOPC and JCOMM for recommendations about needed additional activities.

Much of the above will be carried out with the assistance of Steve Hankin’s data access group at PMEL. Coordination activities will be handled via existing groups to the greatest extent feasible; only when it is not possible to make the needed fields available through existing efforts will we undertake OpenDap and LAS activities for these fields.

The PI also will continue to support the design, evaluation and evolution of the global observing system via his leadership activities in OOPC, US and International GODAE, US and International GOOS, GCOS and the WCRP. It is anticipated that these activities will take about 50% of the PI’s time.

3.19b. Progress Report For the Observing System Monitoring Center (OSMC)
by Kevin J. Kern and Steven Hankin

FY 2005 PLANS

This FY2005 plan is based on the assumption that funding will be provided in FY2005 at the same level provided in FY2004. Additional details in regards to the budget are provided in Appendix A. During FY2005 the joint team of PMEL and NDBC will address the following OSMC tasks:

- Continue database and application development to fully support all requirements as identified in the updated OSMC Bubble Chart (see Appendix B).
- Complete the initial development of the GIS-style OSMC-LAS user interface as collaboration between PMEL, NDBC and OCO. Add drill-down capability (clickable maps) to retrieve metadata records, time series and statistical data summaries. Incorporate initial linkages to reference data sets that are available through the OPeNDAP networking (via the National Virtual Ocean Data System) into the OSMC design.
- Add functionality to support the OCO Adopt-A-Drifter program to provide educational opportunities for teachers to incorporate observing systems awareness into their curriculum.
- Incorporate data for the following platforms into the OSMC database: Tide Gauges, Reference Stations, and Transport Arrays, Research Vessels.
- Incorporate data for the following parameters into the OSMC database: PCO_2, Ocean Carbon, Total Depth Temperature (a temperature profile that covers the whole water column), and Sea Level.
- Backfill the database with historical data. (The initial goal is to start all data sources with data since 1 January 2004.)
- Develop a drill down capability within OSMC to get metadata and time series summaries about specific platforms and/or a specific instance of an observation.
- Improve metadata contained within the database for all platforms. An example of the metadata would be contact information (Name, E-Mail, phone, etc) related to the organization that owns the platform or payload and/or instrumentation information related to the platform. The specific metadata requirements will be defined as drill down functionality is developed and based on the needs of the OCC.
- Perform database analysis to determine growth and future requirements to support the OSMC over a five-year initial operations period.
- Resolve issues related to duplicate reporting of observations when updating the OSMC database.
- Assess the impacts of data correction/changes resulting from the QA/QC process of the data provider and how it will impact the integrity of the OSMC database.
- Continue to support OCO initiatives as resources permit for briefings, presentations, and ad-hoc requirements.
- Finalize software procedures to perform monthly (currently) updates of static images using NDBC OSMC database and NDBC systems.
- Continue to support up-to-date animations and pre-created graphics as needed that illustrate the evolution of the performance of the Observing System.

3.20b. An Indian Ocean Moored Buoy Array For Climate

by M.J. McPhaden

FY 2005 PLANS

In FY 2005, we will acquire sufficient equipment to replace the 3 ATLAS and 1 ADCP mooring along 80.5°E. Informal discussions with Indian colleagues indicate that enough sea days will be available on the *Sagar Kanya* in the September-November 2005 time frame for us to revisit these sites and 0°, 90°E for recovery and redeployment operations.

All data telemetered in real time from the moorings deployed in 2004 will be displayed and distributed by the TAO Project. Web page development will thus be a priority activity in FY 2004. In addition, the ATLAS mooring data will be placed on the GTS by Service Argos.

3.21b. Pilot Research Moored Array in the Tropical Atlantic (PIRATA)

by M.J. McPhaden

FY 2005 PLANS

Moorings at the 10 PIRATA sites will be recovered (if found) and new moorings deployed in FY 2005. Brazil has proposed a cruise in April 2005 to service the 5 westernmost sites. France has had some difficulty in identifying dedicated ship time, but has proposed a combination of a chartered vessel and piggybacking on another French cruise to maintain the 5 easternmost moorings. These cruises are scheduled for May and June 2005, about 15 or 16 months after the 2004 deployments. While ATLAS moorings are designed for nominal 12-month deployment duration, battery capacity and hardware integrity permit longer deployments. Delayed cruise schedules will impact data return though, especially in light of the fact that 2 moorings in the eastern Atlantic are not transmitting and may be lost.

PIRATA is nearing the end of a 5-year PIRATA consolidation phase. The future of PIRATA will be discussed at the PIRATA-10 meeting, to be held in Fortaleza, Brazil in December 2004. Proposals for enhancements and expansions of the array will also be discussed. The PI plans to attend this meeting.

3.22b. The University of Hawaii Sea Level Center

by Mark Merrifield

FY 2005 PLANS

We will continue the operation and maintenance of our tide gauge network. Planned station visits during FY2005 include Salalah, Masirah, Cape Verde, Dakar, Rodrigues, Port Louis, Point La Rue, Kapingamarangi, Yap, Saipan, Mombasa, Lamu, Zanzibar, Nauru, and French Frigate Shoals. As always, the stations visited may vary depending upon maintenance needs. French Frigate Shoals will require installing a new station when the sea wall is ready. The center will also continue to upgrade global network sites to acoustic and radar sensors in place of the older float gauges, and replace older DCPs with newer models capable of transmitting at higher baud rates. Many of the existing UHSLC installations are built on World War 2 era structures, and these structures are deteriorating. The UHSLC plans to either build new stations on newer structures or in remote areas we will begin building our own piers. We will deploy non-contact radar sensors where feasible. The UHSLC also plans to rebuild its spare part stockpile. This will enable us to respond quickly and efficiently to problems.

The UHSLC will continue as a partner in the ODINAFRICA project, which will oversee the installment of 10-20 new tide gauges in Africa. We will provide technical support to host countries seeking to reestablish dormant tide gauge stations in Sri Lanka, India, Argentina, and Indonesia, and coordinate with colleagues in Brazil to install a second satellite transmitting gauge and tie continuous GPS stations to the new tide gauge installation at Salvador. We could accelerate these installations with more resources (see add task 1).

The center is in the process of hiring a new technical staff person who will fully implement the real-time database in support of GODAE. We will continue to explore ways to expand the CLIVAR/GLOSS fast delivery and real-time data sets. Our ultimate goal is to provide the entire GCOS and ultimately the GLOSS tide gauge network in real or near-real time. The center will continue upgrading the data sets available on NOPP's NVODS LAS, and work with PMEL and the NODC to support the CDP, which enables researchers and others to access the products developed by the various elements of the Climate Observing System over the Internet without having to log on to multiple web sites. We will also continue working with IPRC to ensure that the JASL delayed mode observations are available through the APDRC servers. We expect that these efforts will provide the UHSLC datasets in common and easy to access formats for researchers and modeling centers.

The center will begin to upgrade the existing JASL metadata format into Federal Geographic Data Committee (FGDC) compliance. This will allow more thorough documentation, enhance computer searches, and facilitate data exchange.

Our research effort will include studies utilizing the GPS ground motion dataset at each of our tide gauges. Absolute sea level trends will be provided at all GPS@TG stations, and we will continue to work on defining secular and other relative sea level trends at in-situ stations, including trends of various maxima values. This work includes the calculation and correction for any local network trends identified by benchmark surveys, and the incorporation of SAR-based ground motion estimates.

We will submit a paper on the Tuvalu sea level rise analysis and an assessment of GPS vertical land motion rates in the Pacific. The center will continue collaborating with Philip Woodworth of the Proudman Oceanographic Laboratory and Gary Mitchum of the University of South Florida on an annual report describing sea level variability for the previous year.

3.23b. Satellite Altimetry

by Laury Miller

FY 2005 PLANS

All FY04 tasks will continue into FY05 and beyond, and level funding ($240K) should be sufficient to support them. Most of the support for LSA is derived from NESDIS base, but the increment from Climate Observation enables significant enhancement of altimeter data for climate applications and research. If the FY06 Jason-2 new initiative is ultimately approved by Congress, LSA would receive some new funds.

LSA is also involved in a collaboration with Dr. Gary Lagerloef (Earth Systems Research), Dr. Gary Mitchum (South Florida University), and several other partners, to operate a near-real time processing and data center which is providing maps of total surface current (geostrophic plus Ekman) in the tropical Pacific Ocean. This is being done by combining sea level from altimeters and wind vectors from scatterometers, using quick-look versions of both data types. These products are updated daily as part of a NESDIS operational activity, and results are distributed via a dedicated web site: http://www.oscar.noaa.gov/

3.24b. The Global Drifter Program

Global Drifter Measurements of Surface Velocity, SST and Atmospheric Pressure

by Peter Niiler

FY 2005 PLANS

Anticipated requirements to maintain the "Global Surface Drifting Buoys Array" at status quo:
With the current attrition rate of the global drifter array due to all causes (e.g., deployment failures, picked up, gone ashore, stopped working, etc.), the array needs effectively to be replaced every year. This conclusion is based on the observation that a global array of about 600-650 drifters was in the ocean during 1997-2002. During this time about 420 drifters per year were acquired by *GDP*, 100 drifters from individual research proposals and 120 drifters from the operational meteorological community, or a total of about 640 drifters each year were deployed.

To keep the status quo of US contribution of a 900-element drifter array in the ocean in 2006, GDP needs to acquire about 740 drifters in FY 2005. Additional 160 drifters come from ONR and CORC funded activities.

The continue to maintain the global SST/Velocity array of 1250, the required drifters can be acquired within the expected stable, or level, FY 04 funding of the NOAA climate observing system for FY 2005. Two add tasks are proposed:

Logistical Requirements:
Presently, most of the global drifter array is deployed from the "Volunteer Observing Ships" (VOS) and research vessels. Requirements from the NOAA Hurricane Center are also to deploy Minimet drifters in front of major hurricanes that threaten the US mainland. Continued air-deployments will be requested from C-130-J 53rd National Air Force Reserve "Hurricane Hunter Squadron", stationed at Keesler AFB, MS. In 2005, 20 air-deployment containers will be prepared at SIO which contain either Minimet wind drifters (12) or Minimet wind drifters with a thermistor-chain attachment (8). The request for the services of the 53rd will be made through Dr. Peter Black of the NOAA Hurricane Center. In September 2004, the 53rd successfully deployed 23 drifter containers in front of Hurricane "Frances".

Technical Developments and Data Enhancements:
In 2005, in cooperation with the CORC project, we will continue to pursue the construction and evaluation of SSS sensors. SeaBird Microcats attached to 12 SVP-B drifters will be deployed in the North Atlantic with the cooperation of the French Meteorological Service in the Bay of Biscay; they have offered to retrieve these for post-calibration during their regular cruises to service moored buoys west of France.

The CORC project will merge with the Global Drifter Program in FY 06. The objective in FY 06 will be to construct about 300 SVP-SSS drifters for the calibration and validation of the "Aquarius" SSS satellite that will be launched in 2007. The cost of the SVP-SSS drifter will be about $3400 in addition to the cost of a SVP-Mini drifter. About $1,100,000 will be sought from NOAA to fund the drifter component of the "Aquarius" cal-val program. NASA will fund the data analysis and interpretation.

Drifter velocity data enhancements will continue. We propose to continue the wind-slip corrections to the drifter velocity data set on a six-month basis and make requested gridded data available to the scientific community. Arrangements will be made to store these wind corrected data files at the AOML Global Data Center for submission to MEDS Canada, an activity that is now possible under the careful eye of Dr. Rick Lumpkin of AOML.

3.25b. Climate Variability in Ocean Surface Turbulent Fluxes

by James J. O'Brien, Mark A. Bourassa, and Shawn R. Smith

FY 2005 PLANS

- Test and implement new automated quality control of 1˚ input data
- Complete 1978-present 1° wind analyses for tropical Pacific, Indian, and Atlantic Oceans
- Evaluated methods for extending tropical Pacific and Indian Ocean fields prior to 1978
- Begin flux field production
- Calculate wind uncertainty fields for completed ocean basins
- Continue comparisons of FSU winds and fluxes to available products
- Complete development process for of satellite scalar winds
- Complete development process of micro-wave satellite SST
- Develop an objective technique for determining appropriate periods for temporal averaging of satellite data.

We anticipate analyzing gridded monthly flux fields for the Indian and Atlantic Oceans for spatial temporal patterns of variability. We will investigate the connection of known source of variability (e.g., NAO, ENSO, AO) to the variability in our gridded fields.

Our ocean model for the Gulf of Mexico will be forced with realistic fluxes (stresses, turbulent surface fluxes, and radiative fluxes for several purposes. One such purpose will be to test the energy budgets in the ocean model. Very preliminary tests are encouraging. If the testing is successful, we anticipate being able to examine the modeled heat fluxes for extreme wind speeds, a regime for which there are many interesting questions yet to be resolved. We will also be able to better examine the fate of fresh water input from rivers, as well as other process studies.

3.26b. U.S. Research Vessel Surface Meteorology Data Assembly Center

by James J. O'Brien, Mark A. Bourassa, and Shawn R. Smith

FY 2005 PLANS

- Continue liaison with UNOLS, USCG, NOAA, etc. to establish automated data transfers
- Evaluate and improve data ingest and quality control system based on FY 2004 experience
- Implement automated data transfer for up to 10 vessels
- Investigate four time per day data transfers if desired by user community
- Liaise with international community to lay groundwork for expansion to include international vessels.
- Compare R/V observations to global reanalysis products
- Continue comparison of R/V observations to independent marine platforms

The activities of the RVSMDC will be focused on the SAMOS initiative. Providing routine access to SAMOS observations will support NOAA's goal to "maintain sensor suites on a small core of vessels as the highest quality calibration points for validation of other system measurements" (NOAA 2003). The SAMOS observations will also provide a key part of network of high quality flux reference platforms that were recommended by the WCRP/SCOR Working Group on Air Sea Fluxes (WGASF 2000). Clearly once routine SAMOS data are available, their application for a wide range of validation studies is expected.

The RVSMDC will continue to focus on comparisons between the R/V SAMOS observations, global reanalyses, satellite measurements, and independent marine platforms (e.g., other ships and buoys). We anticipate that the SAMOS data will help quantify biases in the numerical products and inter-platform comparisons should help identify systematic sampling errors present on individual marine platforms.

3.27b. *In Situ* and Satellite Sea Surface Temperature (SST) Analyses
by Richard W. Reynolds

FY 2005 PLANS

During FY2005 we plan to get the OI analysis running at NCDC. This will allow improvements as described below to be implemented. Each improvement will be carefully tested before it is implemented into the operational version. Then the entire analysis from November 1981 (the beginning of multi-channel AVHRR retrievals) to present will be reprocessed. These changes will be then be passed on to NCEP who have agreed to update the operational version.

After the OI is operational at NCDC and tested, we plan to make changes to the OI code as listed below. After each step is complete, the entire analysis from November 1981 to present will be reprocessed and the analysis changes will be sent to NCEP.

a. Make improvements to the OI code.

The OI code has been modified to improved spatial error covariance. This modification will now be tested. Before the OI procedure is carried out, satellite biases are corrected relative to the in situ data. The scales for this correction will also be evaluated. In addition, the present error statistics computed in the OI include only sampling and random error and do not include bias errors. The error statistics will be reevaluated to also include bias errors in the final error estimates.

b. Add new sources of data to the OI and revaluate the improvements.

In Reynolds et al. (2004) we have already evaluated the use of microwave SST data from TMI. In the new version of the OI it is now possible to add additional sources of data. We plan to first focus on the microwave satellite SST products from TMI and Advanced Microwave Scanning Radiometer (AMSR). Then additional IR satellite products will be considered. We believe that the use of these data will produce an analysis with lower errors. After this stage is complete additional in situ data from oceanic profiles will be added. Preliminary testing has shown that these in situ data will have a minimal effect because they are so spares relative to surface marine data. However, these data need to be added to assure that no source of accurate SST data is neglected.

c. Modify the OI resolution.

After these two steps are completed, we will investigate the impact of improved temporal and spatial resolution. It is expected that these improvements will be modest (a daily analysis instead of weekly and a 0.5° analysis instead of 1°). However, improved resolution will be certainly be possible after December 1997 when both IR and microwave satellite SST data were available.

In addition to these improvements in the OI, we will also continue to monitor the in situ network to determine where new drifting buoy data are needed. This will include seasonal computations such as Figure 1 and computations of the average satellite potential bias error which is used as a metric to evaluate the in situ SST network. These results will be sent to both AOML and of course the OCO.

3.28b. Monitoring Ice Thickness in the Western Arctic Ocean

by Jackie Richter-Menge, and co-investigators/collaborators
H. Melling, J. Overland, R. Lindsay, J. Zhang, and D. Perovich

FY 2005 PLANS

1. Fabricate 4 IMBs (2 for this project and 2 for the companion project "Monitoring the Eurasian Basin of the Arctic Ocean")
2. Recovery and re-deployment of instruments at mooring site CH01.
3. Deployment of 2 IMB buoys in the Western Sector of the Arctic.
4. Collection, analysis and archiving of data from the mooring and buoys.
5. Completion of a webpage, which will present the data in a near real time format.
6. Presentation of results at national and international meetings.
7. Initiate plan to assimilate ice thickness data in sea ice dynamics models, used to forecast ice thickness distributions in the Arctic Basin.

3.29b. Monitoring Eurasian Basin of the Arctic Ocean

by Ignatius G. Rigor

FY 2005 PLANS

1. Ice Mass Balance buoy deployments
   1.1. Two buoys have been shipped to Kirkenes, Norway. These buoys will be deployed during the Nansen and Amundsen Basin Observing System (NABOS),
   1.2. http://www.frontier.iarc.uaf.edu/NABOS/index.php) 2005 cruise.
   1.3. One buoy has been shipped to Gothenburg, Sweden for the Swedish ice breaker Oden's 2005 Arctic Ocean transect from Bering Strait to the Greenland Sea. We plan to purchase additional buoys for this deployment opportunity if resources are available.
   1.4. Two or more buoys will be deployed by aircraft in collaboration with the NPEO in April 2005.
2. Data collection and analysis.
3. Presentations at national and international meetings.

3.30b. High-Resolution Ocean And Atmosphere PCO_2 Time-Series Measurements

by Christopher Sabine

FY 2005 PLANS

Anticipated Requirements to Maintain the Network at Status Quo:

The program currently maintains two different types of pCO_2 systems. The systems at 155°W, 0° and 170°W, 2°S have been in operation since 1997. These systems use an older dual path LiCor that is significantly more expensive than the LiCor 820 used in the systems built by PMEL. The standard MBARI systems also only provide a ΔpCO_2 measurement instead of individual air and water values. Over the past year, the LiCor 820 systems have proven themselves to be robust and accurate. Having the absolute measurements of water and air pCO_2 separately provides additional information for interpreting carbon flux variability. This together with the reduced cost of the new systems makes them a better choice for the development of the moored pCO_2 network. The MBARI pCO_2 systems, however, are integrated with a biooptical package that is funded by NASA. The NASA program has one final year of funding, therefore, we anticipate continuing with the historical systems at 155°W, 0° and 170°W, 2°S for one more year before converting to the PMEL systems. The MBARI budget reflects the continuation of these moorings for an additional year, including the need for two more 6-month recovery/deployment cycles.

The TAO buoys at 125°W, 0° and 140°W, 0° are scheduled to be replaced with new buoys in February/March of 2005. The pCO_2 systems at these locations will need to be replaced at this time. Replacement systems exist, but they have just recently returned from sea and will need to be refurbished and recalibrated. We expect that the refurbished systems will not need to be replaced for a year, but typically the ship makes a 6-month visit to the buoys to check on their status. Some minor maintenance may be required at that time.

The Hawaii mooring is recovered every 4 months, spends a week on shore being refitted, then is deployed again. The existing pCO_2 system will need to be replaced at the next recovery in November/December 2004. The first year budget for the HOT system only included money for one system, with plans for a second system to be built in FY05. Given the need for an early replacement of this system, we will use one of the refurbished systems from TAO for this deployment and build a new system to replace the shortfall for the spring TAO deployment. Two additional recovery/deployments are scheduled for FY05. The pCO_2 system is designed to operate for a year so we do not anticipate having to replace the system, but the system will be thoroughly evaluated with each recovery.

In addition to the mooring measurements, we have also been collecting nutrient and chlorophyll measurements on the TAO cruises. This work is an effort to evaluate the biological component of the pCO_2 variability we observe as part of both the mooring and the underway pCO_2 programs. Through this work we can better understand the new autonomous measurements that need to be developed for the moorings to evaluate the controls on the CO_2 fluxes. This work requires that a technician, supplied by MBARI, participate on each of the TAO cruises. In addition to taking care of the shipboard measurements, this technician will be primarily responsible for ensuring the proper deployment of the pCO_2 moorings.

New Data Collection:

The long-term vision for the moored pCO_2 array is to populate the OceanSite moorings with pCO_2 systems. The TAO OceanSite location at 170°W, however, is on the equator not at 2°S where our pCO_2 system is currently located. Logistical considerations associated with the TAO and MBARI systems prevented the preferred deployment at the equator when this site was first instrumented in 1997. Since the variability signals we are investigating are strongest at the equator, we will build and deploy a PMEL system at 170°W, 0° in FY05 to start establishing a time-series record in this critical location. This system will have a one year overlap with the historical system at 170°W, 2°S so we can investigate the correlations between the historical trends observed at 2°S and the future observations at the equator. After FY05 we anticipate ending the 2°S measurements unless compelling science is observed during the overlap period.

Logistics Requirements (e.g., ship time):
There are no additional ship-time requirements for this project at the current time because all of our systems are deployed on existing platforms. The ship-time required to maintain these platforms has already been justified and allocated for the core mooring programs. This program does require the presence of one additional participant on the TAO cruises to make the shipboard measurements and to install and activate the pCO_2 systems upon deployment. This person will be supplied by MBARI and is expected to assist in the mooring recovery/deployment when not occupied with duties related to this program. PMEL is also paying partial salary to a TAO technician, Patrick A'Hearn, to assist with the moored pCO_2 systems. One person is required to install and activate the pCO_2 system on the HOT mooring cruises. We have trained one of the technicians from the Hawaii Ocean Time-series Program to handle these duties in exchange for covering a portion of his salary. The actual time required to set up the pCO_2 system is minimal, so it is much more efficient to have someone already associated with the cruise to take on these additional duties.

Expected Scientific Results:
Over the past year, we have been evaluating the impact of tropical instability waves on the surface water pCO_2 in the equatorial Pacific. There appears to be a strong anti-correlation between sea surface temperature and surface pCO_2. Over the next year we anticipate quantifying this relationship and writing a manuscript describing the mechanisms controlling these short duration variations. There are also signs that we may be entering another El Niño year. We will be watching carefully to understand the timing of the CO_2 signal relative to the temperature anomalies associated with the El Niño. Although we do not yet have CO_2 sensors all the way across the Pacific, we will be able to use the four sites to evaluate the magnitude of the signal at different locations and how it propagates across the Pacific during its initiation. With the concurrent measurements off Hawaii we can start to examine the extra-tropical connections with the El Niño. In particular, we will be looking to understand the timing and mechanisms behind the connections to processes in the equatorial Pacific. The Hawaii system will also provide the first high-resolution pCO_2 time-series measurements over a full annual cycle at this JGOFS time-series station. Careful comparison against the Hawaii Ocean Time-series shipboard data will provide an assessment of any biases that may be present in the seasonal flux estimates calculated from the 15 years of monthly measurements of dissolved inorganic carbon and total alkalinity at this site.

3.31b. *Document Ocean Carbon Sources and Sinks:* Initial Steps Towards a Global Surface Water pCO_2 Observing System, and Underway CO_2 measurements on the NOAA ships *Ka'imimoana* and *Ron Brown* and RVIB *Palmer* and *Explorer of the Seas*

by Rik Wanninkhof, Richard A. Feely
with Nicholas R. Bates, Frank Millero, Taro Takahashi, and Steven Cook

FY 2005 PLANS

Requirements to maintain the network at status quo:

pCO_2 on research ships: the requested funding level can maintain status quo but focus will have to be on upgrading instrumentation that is beyond the useful lifespan. The added instrumentation cost will be recovered through reduced personnel cost currently expended on emergency repairs.

VOS: This effort is not yet fully operational and is behind schedule in outfitting as proposed because of late receipt of funds and longer lead times for instrument development and procurement. Scheduled outfitting can be completed with funds requested. See add task for requested augmentations.

Logistics requirements:

Research ships: The underway CO_2 efforts have been one of the first chemical measurements to run nearly unattended on the research ships. However, several of the ships have instrumentation for other projects. This has put a strain on space and ship resources since these measurements are not an integral part of the ship's projects and there are increasing pressures maintaining these efforts. More formal arrangements regarding sustained operations on research ships should be implemented onboard the *Brown* and *Ka'imimoana*.

VOS: Installation and maintenance of pCO_2 systems on VOS has proven to be a more substantial task than anticipated. There are a significant amount of uncertainties regarding interactions with ship's command, space availability, access to ship's etc that make the effort more time consuming and costly than originally anticipated. For example, in some cases ship riders are required to provide support for the instrumentation during the voyages. Despite this, ships have been found to carry our equipment on the proposed lines. For these efforts, auxiliary measurements (air flask measurements, XBT, fluorometry, plankton recorders, meteorology) are very beneficial for interpretation of results. In some cases this is becoming problematic because of overburdening the ships with projects.

The NOAA COSP underway pCO_2 program is the largest coordinated effort in the world. A major responsibility the group has taken on is to promote uniform instrumentation and data reduction and data dissemination protocols through informal and formal avenues. The formal mechanism has been through the IOCCP, Carbo-Oceans and PICES working group 13. We have been instrumental in developing the autonomous underway pCO_2 analyzer and finding a person to build them. This was done in collaboration with the University of Bergen. We are now seeking to find a commercial vendor to build the instruments and to find innovative means for product support.

New data collection methods:

The second generation of autonomous pCO_2 systems has been designed and built which, in time, will be capable of operating autonomously on VOS. The system has been designed such that data can be telemetered to shore and two-way communication allows instrument commands can be sent to the instruments on the ships. Systems on the research ships will be upgraded to this new system when funding allows.

Expected scientific results:

The work is in support of creating:

1. Seasonal CO_2 flux maps
2. Improving mechanistic understanding of the controls on pCO_2.
3. Increasing data coverage in regions with limited observations to improve the global pCO_2 climatology.

The mechanistic studies have a focus on providing input for modeling and empirical studies to improve methods of extrapolating/interpolating pCO_2 data in time and space. The papers presented in the reference section are testament to our progress in all three subject areas.

3.32b. Ocean Reference Stations and Northwest Tropical Atlantic Station for Flux Measurement (NTAS)

Robert A. Weller and Albert J. Plueddemann

FY 2005 PLANS

We plan to maintain the three ORS sites through a combination of instrument preparation and testing and mooring turnaround cruises during FY2005. Maintaining three sites will require a pool of hardware (buoy hulls) and instrumentation, ongoing maintenance of the buoys and meteorological and oceanographic instrumentation, fabrication of mooring components, ship time (detailed further under each task), labor for preparation and work at sea, calibrations support, ARGOS telemetry costs, work station and disk support, repair, and replacement, and support of data recovery from the instrumentation, processing, sharing. We are examining shifting from Service Argos to IRIDIUM for data telemetry. Science results are discussed under Task II and III below.

STRATUS FY 2005 PLANS

In December 2004 we will use the NOAA Ship *Ronald H. Brown* to recover and redeploy the Stratus mooring. On the same cruise we will deploy surface drifters and profiling Argo floats. We will also service tsunami moorings for PMEL/NDBC/Chilean Navy (SHOA), take air-sea flux (NOAA ETL) and aerosol (Texas A&M) observations, collect CTD profiles (for colleagues from the University of Concepcion, Concepcion, Chile), meteorological observations for colleagues from the University of Chile, Santiago, and other underway data.

Requirements, Logistics:

A cruise with 6 to 10 days on station at 20°S, 85°W with accompanying transit time.

New data collection methods:

None.

Expected scientific results:

We will have the third year of data processed and quality controlled, and telemetry of the fourth year of data coming in. We will begin to have an idea of the year-to-year variability in the forcing and response and its relation to ENSO variability. We will be providing data to the CLIVAR Climate Process Team working on cloud parameterizations and expect a better understanding of cloud forcing under the stratus to result. We will also be exchanging the ocean data with ocean modelers and examining the realism of ocean models at this site.

NTAS FY 2005 PLANS

Anticipated Requirements:

The NTAS project transitions to the ORS project in FY2005. The FY2005 budget, as outlined below, will be appropriate to maintain the NTAS Ocean Reference Station and sustain the NTAS project through 30 June 2005.

Logistics Requirements:

We will utilize 15 days of ship time on the NOAA Ship *Ronald H. Brown* for the mooring turnaround cruise originating in Bridgetown, Barbados and terminating in Charleston, SC. This cruise is presently scheduled for 9–23 March 2005. We plan to utilize NOAA dockside facilities in Charleston for unloading the scientific gear.

New data collection methods:

None.

Expected Scientific Results:
A publication is anticipated in FY2005 documenting the first 3 years of meteorological observations and bulk fluxes from the NTAS site. The in-situ fluxes will be compared to those available from operational models and satellites, the flux components with the largest discrepancies will be identified, and the reasons for the discrepancies will be investigated.

HAWAII FY 2005 PLANS:
We plan to recover and redeploy in July 2005. Ten days of ship time, on a Hawaii-to-Hawaii leg of a Class 1 ship are needed. The recovery and redeployment will sustain the establishment of a long time series moored perspective at the Hawaii site where a program of sampling from frequently repeated cruises has begun to build an understanding of the physical variability and of the interaction between physics, biology, and chemistry. It is expected that establishment of an Ocean Reference Station at this Hawaii location will accelerate progress toward understanding multidisciplinary science at the site, provide a key anchor site for developing air-sea flux fields in the Pacific, and provide a new regime in which to examine atmospheric, oceanic, and coupled model performance as well as the performance of remote sensing methods. Examination of the performance of models and remote sensing will lead to improvements in products and predictions.

3.33b. Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic

by Robert Weller

FY 2005 PLANS

Turnaround of the AutoIMET system will be carried out every six months.

The original stand-alone ASIMET modules will all have been converted to the new Auto-IMET systems and these will have been installed on the three active ships, Horizon Enterprise, Columbus Florida, and Sealand Express. A forth ship is scheduled to have a system installed in 2005 making a total of four VOS with Auto-IMET / NOAA SEAS systems that report via Inmarsat C in real time and store one minute data for retrieval every six months. This program is in an operational support mode for the current ships.

Rationale:

The nation is entering a new era of climate research and prediction requiring evaluation and integration of the climate data from VOS (Volunteer Observing Ships) that are now making high-resolution climate observations on a regular basis. Air-sea interaction plays a significant role in this problem and, as time scales increase from weeks, to intra-seasonal, to seasonal, the importance of air-sea interaction increases. The largest mode of short-term seasonal variability in the Earth's climate systems (El Nino) is an air-sea interaction phenomenon. The single most important process in air-sea interaction is the air-sea flux (in come sense, air-sea fluxes are air-sea interaction).

High-resolution climate data has been taken from VOS for several years now as part of an engineering effort to develop the instrumentation and logistical support required. This previous data as well as data being observed on three (soon to be four) VOS requires evaluation and analysis to insure that it is suitable for inclusion in the global climatology data base. This effort is beyond the effort now funded to make the observations and present "first-cut" integrated data on the web for general use.

Proposed Work:

Currently, the VOS program is funded to download the data from the instrumentation, do the time correlation and integration, and post the resulting data set to the web site, but not to do the data quality checking. This task will provide the additional processing and analysis required to:

1) Create a processed and checked, high quality data base of VOS meteorology and air-sea fluxes for public access,
2) Use the processed VOS AutoIMET data to examine how this data compares with surface meteorological and air-sea flux fields from numerical weather prediction (NWP) models and other flux data sets, including that being developed by Lisan Yu at WHOI,
3) Examine the space/time statistics of the VOS AutoIMET data and of the differences between these observations and other surface meteorological and air-sea flux fields,
4) Analyze the joint statistics of the variability at and differences between the AutoIMET data and the NTAS and WHOTS Ocean Reference Station ASIMET data, working toward the goal of understanding how the combination of high time resolution at a point and the space/time sampling along the ship tracks can best be used to further improve the Yu flux fields,
5) Work with Roemmich and Goni in the analysis of the combined AutoIMET and XBT (and other shipboard oceanographic observations) data to examine air-sea coupling and upper ocean transports by wind-driven and geostrophic flow.